Maximising seaweed concentration by considering different matrixes in food products and consumer sensory techniques.

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Masters by Research (MbR)
August 2018

Word Count: 18,956

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Acknowledgments

I would like to express my gratitude to Dr Jonathan Wilkin for his patience and support throughout my KTP journey and Masters by research. The help given to improve my academic writing and statistics has been invaluable and would not have got to this stage without his reassurance. Also, to Dr John Grigor for his insights into sensory evaluation and assistance with TDS and the rest of the Food and Drink Division for all their support and guidance.

To the production staff with New Wave Foods LTD for organising the seaweed to be harvested, dried and sent to me at Abertay to experiment with in the kitchen. Also, to all my friends and family for all their encouragement throughout my studies and keeping me on track and semi sane along the way.

More importantly to the individuals who participated in all the sensory consumer trials, there would be no data without them.

Abstract

Despite the growth of the functional food convenience and snack market, seaweed containing food products have been limited to small quantities of imported produce; mainly as a salt replacer rather than a main ingredient. To improve this situation, this work investigates UK consumer expectations and insights into seaweed containing products. This research explores the possible application of seaweed as a functional ingredient with unique nutritional, textural, and sensory characteristics, offering innovative food design solutions. In addition, the study aimed to identify the maximum concentrations of seaweed in a food-based application for rehydrated and dried edible Scottish seaweed with the intention of encouraging seaweed consumption.

The first stage of this study investigated rehydrating several dried seaweeds sent to Abertay, Scotland from the factory and harvest site in Wick, Scotland. Once the data was recorded appropriate seaweeds were selected for varying food products based on volumes, accessibility, seasonality and nutritional properties. Different concentrations (20% and 40%) of *Undariapinnatifida* (Wakame) were incorporated in a salad, 15% *Himathalia Elongate* (Sea Spaghetti) in a pesto, 30% *Himathalia Elongate* (Sea Spaghetti) in crisps and 5, 10, 15 and 20% *Undariapinnatifida* Wakame) and *Himathalia Elongate* (Sea Spaghetti) in crackers.

During this study, lower concentrations of seaweeds were considerably more acceptable to consumers in the salads and crackers. Interestingly a higher fat concentration of the pesto also was more consumer acceptable, and various flavours of the crisps, which were determined by sensory analyses techniques. These results will help the food industry promote seaweed into the food market with a range of successful healthier products.

As a result of the new product development in this study the 20 % seaweed salads, seaweed crisps and seaweed pesto added to pasta are being up scaled commercially. They are now available to purchase online and in health food stores such as Ocado, Real Foods and Whole Foods and other smaller retail outlets.

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1. Introduction

There have been important developments in the innovation of food products as a result of an increased amount of new and novel foods appearing on the market (Bäckström *et al*., 2004). Product innovation is regarded commonly as a major triumph in a competitive global food industry although difficult and risky. However, these new food products have a reported high failure rate of around 70-80 % according to Gresham *et al*. (2006). Innovation is seen as a beneficial strategy in this sector, particularly for the enhancement of consumer acceptance and the promotion of successful market introductions (Buisse and Siebert, 2018).

One of the major challenges in introducing a new food product to the market is envisaging how acceptable it will be to consumers. This acceptability is critical for the development and success of food products (MacFie, 2007). The process by which a consumer accepts or rejects food has a multi-dimensional nature (Costell *et al.* 2010). It is described as the result of the interactions between an individual and food at a certain moment (Sheperd, 1989). Consumer's responses to foods is a complicated, dynamic and varied field of study especially in a novel, complex food matrix (Lawless and Heymann, 2010).

Several factors determine consumer's acceptance to a food product, which include convenience, price, packaging and trust. Trust is vital for acceptance of functional novel food, as consumers must trust any health claims the producer has provided. (Verbeke, 2006). This is echoed by Backstrom *et al*. (2003) and Huotilainen *et al*. (2006) proclaiming distrust of new innovative products can inhibit consumer acceptance. It is vital for the survival in an increasingly competitive and diverse industry to recognise the aspects, which establish food acceptance in different cultures and identify potential opportunities for successful food product development encompassing a global acceptance across cultures (Meiselman 2013; Moskowitz and Beckley, 2012).

As our population is aging and rising, demand for food by 2050 is believed to increase by 70% annually (Forster and Radulovich, 2015). Sustainable production methods for food and energy are essential if we do not desire to convert all available nature into agricultural land. (Wolkers, 2011)

The current market for seaweed products is steadily making the transition from a niche sector into mainstream. There has been wider media coverage regarding the health benefits of seaweed and high profile worldwide chefs have been using it as an ingredient. Also the addition of the expanding health food industry has increased the demand for seaweed intake. However, this is being held back by limited fresh seaweed on offer and lack of product innovation. Current products using domestic seaweeds frequently lack a clearly defined and understood usage for the consumer. Imported seaweed products tend not to be processed for Western consumer tastes and often limited to narrow Nori based products. UK product offer is limited compared to some European countries and especially behind USA, where seaweed is a fast-growing market (Peinado, 2014).

In 2014 the total global production of seaweed was 27.3 million tonnes (McHugh, 2003) this rose to over 30 million tonnes in 2016 with a USD value of over 10 million. This global seaweed aquaculture production dominates almost 20% by weight of the world's marine aquaculture production (Cottier-Cook *et al.,* 2016; FAO, 2017). With most of this production taking place in Asia.

Norway, France and Ireland dominate the European seaweed market with Portugal, Spain and the UK being very small suppliers and producers. However, seaweed is gradually gaining popularity within Europe as more people start to embrace the Asian diet. This diet incorporates between 10 to 25 % of seaweed food intake in most Japanese people (Peinado, 2014). Moreover, current consumption of seaweed products in Europe is increasing with approximately 15–20 edible algae species marketed for human consumption. (Peinado *et al.* 2014).

The challenge for new product development with seaweed is creating products designed specifically to appeal to European tastes and eating habits. This is both a technical challenge and a neophobic consumer challenge, and seaweed products need to ensure flavours and textures appeal specifically to European tastes. This can be measured based on Risso *et al* (2017) finding that tastes differ using a bio-cultural approach to the study of food choice by investigating the contribution of population and culture. Significant differences were distinguished in food habits across populations. Three bitter foods and perceived bitterness of stevioside were significantly higher in Northern Europeans compared to Maghrebis, Sri - Lankans and Italians. The challenge regarding consumer acceptability of seaweed is apparent from the seaweed's texture, aroma and bitter and salty taste.

It is evident the species and quantity of seaweed in a food product has varying attributes throughout the swallowing process. This study further investigated consumer acceptability of food products containing various levels of seaweed.

This research project is industrially linked and was supported through a Knowledge Transfer Partnership (KTP); the work was undertaken with the Small to Medium Sized Enterprise (SME) New Wave Foods Ltd. The project came about from extensive market intelligence with the start-up company New Wave Foods ltd who then required further research at Abertay University for new product development. The aim of this KTP was to develop two value added consumer acceptable products; which were a nutritionally balanced salad option and a snack product. The outcomes of this piece of research directly affected the company by increasing their product portfolio and ultimately profit.

This study was undertaken with the following objectives:

1. Evaluate the addition of seaweed into new food product through the NPD process to create a range of consumer acceptable food products.

2. Assess the optimum concentration of seaweeds in a range of food products in order to maximise its ratio and its consumer acceptability.

3. Appraise Temporal Dominance of Sensation (TDS) as a practical tool to assess and optimise the concentration of seaweed within a new seaweed product.

Due to market intelligence and market research within the company, salads, pesto, crisps and crackers were used as food vehicle to incorporate seaweed into a mainstream diet. Additional products such as seaweed popcorn, seaweed salsa verde, seaweed pasta and seaweed tea were also trialled in the NPD kitchen. The final selection of seaweed used for these products were Wakame and Sea Spaghetti due to availability annually at the harvesting sites in Wick. These species would grow and be harvested in large volumes to keep up with NPD demand and be nutritionally and financially viable.

2. Literature Review

2.1 Seaweed Harvesting

The harvesting of seaweed is regulated by the EU and monitored by scientists and regulators for prior biodiversity assessments. Licenses are granted for different harvesting locations and size. Manual and mechanic harvesting is carried out depending on the location, equipment and the use for the company. In this research the company New Wave foods manually harvest their seaweeds by cutting it to allow for regrowth during low tides for ease of access. The seaweed is then put in bags, transported from shore to factory, where it is washed and dried.

Good water conditions are key to growing high quality seaweed that is fit for human consumption. New Wave Foods harvesting sites are based around the far north of Scotland, a remote area of low population density. The sites were selected after extensive research and surveys of the Scottish coastline. To achieve highest quality raw material the site selection criteria included many risk assessments including distance from areas of possible contamination (urban areas, ports, major fresh water inputs etc.). Seaweed must be harvested from exposed areas with high water exchange allowing for renewal of nutrients and avoidance of fouling. Regular quality tests are taken at each site to ensure no local pollutants, heavy metals, pesticides, microorganisms. Harvest areas must have low human activity. All the seaweed is hand harvested by trained harvesters where the seaweed is selected and cut by hand for quality and re-growth. Each species is only harvested in season, ensuring high quality and no fouling or bleaching.

2.2 Seaweed Production

As the world's population is aging and rising, demand for food by 2050 is believed to increase dramatically. Globally over 290 species of seaweeds are currently consumed, mostly for food and the production of hydrocolloid, medicine, fertilizer, paper and animal feed (Forster and Radulovich, 2015).

Seaweed or edible algae are a rich source of micronutrients that are found on the coast of many countries and they are valued as marine plants (Keyimu, 2013), according to Bequette and France (2004) there are 45,000 species of marine macro algae or Seaweed, plant like organisms belonging to three different groups: Brown (*Phaeophyceae*), Green (*Chloropgyceae*) and Red (*Rhodophyceae).* Green algae are commonly present in freshwater and even terrestrial locations such as rocks, walls and tree bark, whereas red and brown algae are almost exclusively found in marine environments. Seaweeds are diverse in nature in regards to their size, shape, colour, seasonality and composition. Apart from colour, these seaweed varieties differ considerably in quality, consistency, and nutrient content. In addition the chemical composition of theses seaweeds vary with environmental conditions, habitat, species and maturity (Ortiz *et al.,* 2006)

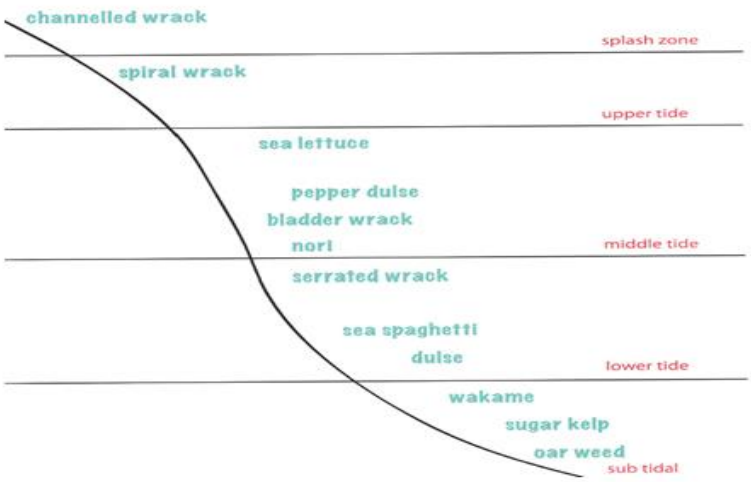


Figure 1: Tidal zones where common seaweeds are found

Common seaweeds found on the Scottish coast and their tidal zones are highlighted in Figure 1 where they are harvested during the appropriate tides for accessibility.

2.3 Seaweed Uses

In Europe, seaweeds have been consumed for decades, but its flavours and textures may carry a negative perception among people (Mendis and Kim 2011). Seaweeds are rich in a wide variety of bioactive components, contributing to many health benefits, and accordingly can be classified as a source of functional food ingredients (Gannam and Cox, 2013). Nevertheless, seaweed remains largely unexploited as a food source in the Western diet and is principally used to provide extracts such as agar, carrageenan, and alginate. Additionally, the aquatic plant is used in some regions as fertiliser, animal feed, cosmetics and medicine (Kenicer *et al.* 2000). McHugh (2003) further describes seaweeds to be significant marine bio resources utilised for fertilisers, biofuels, and hydrocolloids extraction. An emulsifying gelling agent where the alginate is further used for the cosmetics and pharmaceuticals industry (Maneveldt, 2015).

According to Cox and Ghannam (2013), its widespread consumption in the East can be accredited to its unique flavours and numerous nutritional benefits. Thus, high nutritional benefits, alongside the growth of the health/food industry has enabled the revival of seaweed in the diet of the UK population.

Around 95% of the current global seaweed production currently comes from Asia, mainly due to its use in Asian cuisine (Scottish Enterprise, 2017). In 2004, 99% of the world's seaweed was produced by just eight Asian countries (Dhargalkar and Pereira, 2005). This inherently suggests that lack of exposure to the product is a factor in its lack of consumption in Europe, significantly due to culture. Western consumers are possibly unacquainted with eating seaweed other than sushi. Nevertheless, seaweed-flavoured food products are superfoods that appear to be trending in Europe. A survey conducted by Mintel (2016), highlighted further that seaweeds health benefits appealed to European consumers, as 58% of German consumers and 44% UK consumers either tried or would be interested in trying algae as a source of protein.

People are now becoming aware of seaweed's potential as a food source with evidence suggesting that it contains a source of nutrients, including many essential vitamins and minerals (Roohinejad *et. al*., 2017; Cox, 2013; Lage-Yusty *et al*., 2012; Hanjabam*et. al*., 2016; Kadam and Prabhasankar, 2010; Tibbetts *et al*., 2016). Also containing an abundance of fibre, carbohydrates, protein and essential fatty acids

(MacArtain *et. al*., 2007). This functional and sustainable benefit will enable seaweed to have considerable scope to be incorporated into the UK diet.

Taking into account the wide spread data available on the functional attributes of seaweed; it appears to have extensive uses and potential incorporation into many food products (Roohinejad *et al.,* 2017). With the application of seaweed and seaweed extracts added to several food products could potentially increase the nutritional value, improve texture and sensory profiles of foods such as meats, bakery and dairy items.

2.4 Neophobia

Nevertheless, seaweed is a challenge as these products do not normally appeal to Western tastes, which can be due to neophobia. Neophobia is one of the many factors affecting acceptability of innovative products. Unfamiliarity and lack of exposure, is a strong barrier in food choice and can evoke negative responses to new foods. Prescott (2004) states that particularly in a cultural context, acceptance of novel foods varies depending on previous experience where repeated exposure can enhance sensory perceptions.

Dovey *et al* (2008) defines food neophobia as a reluctance to eat unfamiliar foods, although despite being extensively investigated the means behind the rejection of foods have not been clearly identified. (Lafraire *et al.* 2016). Neophobia can have a considerable impact on the quality of our diet, as it is such a crucial determinant of our food choices. It can also have a detrimental effect to new food products entering the market. As stated by Barrena and Sánchez (2013) new food products high failure rate is an added result developed from negative attitudes with regard to food and food neophobia.

2.5 Health Benefits of Seaweed

According to studies conducted in the south-east of Asia, seaweed has been found to suppress diseases such as cancer and diabetes, as well as heart problems (Brown *et al.* 2004). As stated by Kadam and Tiwari (2014) seaweeds are a good source of dietary fibre, reporting that Laminarin, a molecule found in brown algae possesses functional dietary fibre activity. Ruperez and Saura-Calixto (2001) established that higher amounts of total dietary fibre (36.12 % dry weight) were contained in *Laminaria digitate* in comparison with the species *Chondruscrispus*, *F. vesiculosus Porphyratenera* and *Undariapinnatifida*.

In addition, an early study by Teas (1982), indicated a non-digestible fibre found in Laminaria was a significant factor in the contribution of reduced breast cancer incidences reported in Japan. More recent studies by Ji *et al*. (2012), and Ji and Ji (2014) indicate Laminarian performs as an efficient and effective anti-tumour agent.

Moreover, research reviews have identified the anti-inflammatory properties and immunostimulatory activity of marine algae (Lee *et al*.,2012; Neyrinck *et al*., 2007; and Jaswir and Monsur, 2011). Furthermore, some seaweed molecules have been understood to have anticoagulant properties (Miao *et al*.,1995; Shanmugam and Mody, 2000) and research by Tsiapali *et al*., (2001), Balboa *et al.*, (2013) and Choi *et al*., (2012) highlighted the antioxidant activity in certain seaweed bioactive compounds.

Gupta and Ghannam (2011) and Kadam and Prabhasankar (2010) proclaim seaweeds to be a rich source of micro and macronutrients. Seaweeds are also recognised as an exceptional natural source of iodine (Nagataki 2008; Zimmermann 2008).

These micro and macronutrients are highlighted in Figure 2 below:

Figure 2: Seaweeds nutritional benefits (Food Navigator, 2015)

Seaweed has been shown to be a source of bioactive peptides as well vitamins A, B-6 and C, potassium, iron and folic acid. In addition, Fleurence (1999) and Ruperez and Saura-Calixto (2001) proclaim seaweeds encompass high levels of carbohydrates, minerals and proteins. Furthermore, Roohinejad *et al*. (2017) declared that food products containing seaweed could improve their textural and nutritional properties. As seaweed is low in fat and sodium, lower calorie and reduced fat food products can potentially be produced using seaweed as an ingredient.

2.6 Current Studies on Seaweed Products

Several authors have demonstrated the possibility of adding seaweed to familiar foods and evaluating the acceptance of them. Prabhansacar *et al.,* (2009a) investigated different levels (0-30%) of *U.pinnatifida* on nutrition and sensory characteristics of pasta. The pasta containing 20% seaweed had acceptable sensory attributes. Keyimu (2013) then studied the consumer acceptability of noodles with the addition of *Gracilaria* seaweed powder. The overall acceptability was rated and the preferred noodles with the highest nutritional and quality value contained 3% *Gracilaria*.

Overall acceptability of seaweed products based on appearance, aroma, texture and taste was further researched by Cox (2013a). With the addition of 10% of *Himanthalia Elongata* seaweed to breadsticks proved acceptable to the consumer with no significant difference with the control. In addition, Cox (2013b) researched beef patties with the addition of *Himanthalia Elongata*. In terms of overall acceptability, the patties containing 40% seaweed were rated highest, possibly due to improvement in texture and mouthfeel. Furthermore Kwon *et al.,* (2003) researched the addition of varied concentrations (2.5 to 7.5%) of *Laminaria* powder in bread. They reported that bread with the addition of 2.5% *Laminaria* powder was rated highest in consumer acceptability and quality.

Sensory analysis and palatability were investigated in a study by Blouin *et al.,* (2005), children and adults were the subjects of a trial comparing *Porphyra* species in crackers and popcorn. Children found the popcorn samples higher in acceptability although the adults also found it palatable with marginally rating the crackers of higher acceptability. A noticeable flavour was detected and accepted on both *Porphyra* species and food products. This could explain the consumer's previous experience with a similar product to be texturally accepted.

Noodles, meat, and snacks are common food products in the western world and these studies have concluded that the addition of seaweed was acceptable for all sensory attributes. In addition, there is the potential of increasing seaweed consumption among non-seaweed consumers. However, all these studies are based on relatively small amounts of seaweed from Asia or Europe. No studies have been carried out on the acceptability of seaweeds that lie on the Scottish coastline in abundance with ideal conditions for both wild and cultivated growth remaining an untapped sustainable food source.

2.7 Oral Processing

During the eating process, foods properties are altered through sequential (continuous) physicochemical operations. (Chen, 2014). The eating process is described by Chen (2009) as an assortment of operations achieved over a series of stages. These operations change over time and are associated with the sensory perception of food motivated by the physiological procedure of the food matrix breaking down.

Foster *et al.,* (2011) and Boehm *et al.,* (2013) illustrate that oral processing consists of the study of the physics of eating, taking a multidisciplinary approach. Also including sensory perception (Chen, 2014; Saint-Eve *et al.,* 2009) and cognitive function (Grabenhorst *et al.,* 2010).

Taste is a complex mixture of mood-related sensations effected by the physical and chemical properties of foods (Foster *et al.*, 2011). As such, Di Monaco (2016), explains that taste is a combination of several sensations including sweet, salty, bitter, acidic, umami among others. Understanding ingestion, as well as how chemical and mechanical digestion of foods affect a person's food perceptions is important for the food industry (Di-Monaco, 2016). He assesses the process involving the use of muscles in chewing and mastication through which food is broken down, rolled into a bolus by the tongue, and subsequently swallowed to be digested in the stomach. Cox and Ghannam (2013), state that the consistency of the food, its texture, and volume of the bite are dependent on significant chewing cycles to convert the food into a bolus for swallowing. Foster *et al.,* (2011) argue that perception of aroma decreases as the viscosity of foods increases.

Food texture can be extremely important to the consumer (Lawless and Heymann, 2010). It is frequently used as an indicator for food quality unlike flavour and colour. Lawless and Heymann (2010) further describe texture as being perceived by the senses of touch, sight and sound with the consumer using a combination or just one of these senses to asses a food product. These can have a negative or positive influence towards the acceptability of a product.

Marine algae can provide texture and flavour to food, two outstanding characteristics that may open to new culinary innovation (Rioux *et al.,* 2017). The umami taste from Seaweed glutamate content may contribute to the improvement of certain food products.

As texture and mouth feel are deemed critical to consumer acceptability and choice especially when introducing a novel food such as seaweed. The dynamic aspects of this oral process when consuming seaweed products can be captured from a sensory perspective using Temporal Dominance Sensation.

2.8 Sensory Evaluation

The chemical and biological changes in food during oral processing produce several sensory properties over time. Sensory evaluation has been defined as a scientific method used to evoke, measure, analyse and interpret those responses to products as perceived through the senses of sight, smell, touch, taste and hearing (Stone and Sidel, 1993). Sensory evaluation can be a tool used to reduce any risk of products failing. When consumer needs and company requirements are not addressed during the development stage or optimisation of a product, it is unlikely that the new product will be successful if launched (Dimple Singh-Ackbarali and Rohanie Maharaj, 2014).

According to Cox, and Abu Ghannam (2013) it is important for a company to address consumer needs with regards to development of food products to have desirable outcomes following their market penetration. This can be aided through the utilisation of sensory evaluation. Sensory evaluation fundamentally involves the analysis of changes in flavour and texture at each point in time.

According to (Pineau *et al*., 2009), comprehending cultural differences and how they affect food sensory attributes is a crucial part to fully understanding people's preferences. This information is beneficial to the food industry. External factors such as physical surroundings, colours, smells, time, as well as other people, significantly affect individual inclinations (Davy, 2016). Eating behaviour is also controlled by theinternal factors, which could be either physiological or psychological. Physiological factors include hunger and satiety while the psychological factors include learnt cultural practices as well as appetite (Henderson *et al.,* 2003).

2.9 Temporal Dominance of Sensation

An emerging method of sensory evaluation, called Temporal Dominance of Sensations (TDS) has been proposed by Pineau *et al*., (2003). This technique enables the recording of several sensory attributes simultaneously over time. It makes it possible to collect temporal data during one single evaluation for up to 10 attributes on complex food products such as seaweed. It is a valuable tool for future research on the dynamics of texture and flavour perception (Foster *et al*., 2011). This technique identifies and checks the intensity of sensory sensations during time of consumption such as texture and flavour, using the results can be related to the consumer acceptability. In addition, giving a deeper insight towards consumers' perception of seaweed products.

Graphs were generated from the TDS method and highlighted in the results section. The response rate on the graphs is determined from the selected attributes and the time that the participants responded in, within the 40 seconds. Labbe *et al.,* (2009) states a "significance level" line is typically included in every individual dominance rate graph. This is also presented in the results section where this level is defined as the highest limit of the confidence interval for dominance rate expected (Pineau *et al*., 2009).

The higher the attributes dominance rate suggests a higher agreement among participants towards the attribute at that time. A benefit of TDS is that participants require limited training to use this technique if the attributes given are straightforward enough to understand. Products overall liking can be easily measured, and sensory attributes can modulate the hedonic appreciation and/or depreciation during consumption (Labbe, 1999).

The temporal dominance method uses predetermined attributes presented on a computer from which participant's rate the intensity of sensation drawn from the list of attributes on the computer screen. The dominant attribute selected is considered the main perception and is of great importance to the research. If the consumer selects an attribute this is recorded as the strongest attribute and the time measured from the first click until the next attribute is the dominant sensation, thus the temporal dominance of sensation is measured (Pineau *et al*, 2009).

2.10 Conclusion

The majority of literature is based on small concentrations of dried seaweed powdered products predominantly in baked goods such as pasta (Prabhasankar, 2008), noodles (Keyimu, 2013; Chang and Wu, 2008) and breadsticks (Cox, 2013). With various meat products incorporating dried seaweed (Cofrades *et al*., 2008 and Chun *et al.,* 1999).

No consumer studies using TDS for seaweed products or any consumer studies incorporating Scottish Seaweed into food products have been investigated. Currently the common seaweed products on the UK market are salt replacers, seasonings, or supplements. There is considerable scope to introduce new seaweed products such as in salads, pesto, crisps and crackers that will be researched for acceptability in this study. Moreover, culture aspects are important by introducing a new food into that culture and combating neophobia.

3. Materials and Methods

3.1 Rehydration Trials

The effects of rehydration on seaweed species and appropriate rehydration time is essential to determine the texture and use for further development of seaweed products to understand consumer's preference. Dehydrated seaweed food products are usually rehydrated before consumption (Cox, 2012). This is a complex process intended to reinstate the properties of fresh seaweed with a liquid phase.

Following on from Cox's (2012) rehydration trial with varying temperatures, a further investigation into the force required to puncture each seaweed species and the amount of water (by weight) the seaweed absorbed over time was evaluated, whilst considering the sensory characteristics of the final product. This testing will establish the texture and toughness of the product and this will be used to better understand the acceptability of it to the consumer. Texture insight and texture acceptability are significant factors in quality evaluation of food products offered on market (Nabil *et. al*., 2012).

3.1.1 Sample Preparation

The texture analyser was used to investigate the texture after rehydration of five seaweed species: *Undariapinnarifida* (Wakame), *Laminariales* (Kelp), *Saccharina Latissima* (Sugar Kelp), *Palmariapalmata* (Dulse) and *Himathalia Elongate* (Sea Spaghetti). In this report, the common names will be used.

Each sample was cut into 6 cm strips and trimmed to a weight of 1 g. There were 3 samples for each time interval to test. The samples were split evenly and placed into separate bowls of 100 ml deionised water at room temperature. The same time intervals were set, these were 2, 5, 10, 15, 20 minutes. At each interval, the three pieces were lightly dried on a paper towel then individually placed on the texture analyser. Furthermore, to calculate the percentage uptake of water into the system, samples were weighed gravimetrically, recorded and then rated using a 9-point hedonic sensory scale by the researcher.

3.1.2 Texture Measurements

The rehydrated seaweeds were analysed in triplicate after 2, 5, 10, 15, 20 minutes. Objective texture analyses on the seaweeds were performed using a texture analyser (model TA.XT.Plus from Stable Microsystems, Godalming, UK). The test was based on the probe test of spinach leaves used by More *et al.,* (2014) with modifications.

The Film Support Rig (HDP/FSR) with a TMS 2mm needle probe2mm stainless steel needle with 9-10º taper for each sample was set up to conduct a punch test. Each seaweed species was placed between two clamped metal plates to keep them flat and supported by a plate, which exposed a circular section allowing the probe to punch through the sample (Figure 3).

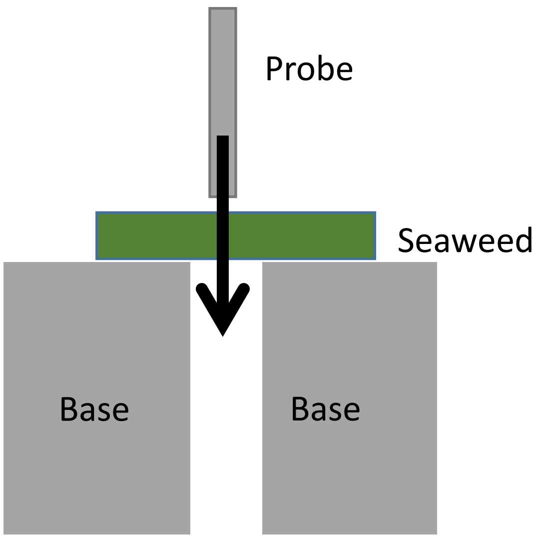


Figure 3: Probe method to measure burst force strength of each seaweed species

During a test, the maximum force to rupture the sample (burst strength) is recorded. The probe penetrated the seaweed at a pre-test speed of 2.0 mm/s, test speed of 1 mm/s as the probe contacted the seaweed and a post-test speed of 10 mm/s using a trigger force in Newtons (N). The probe moved a standard distance of 30 mm and the clearance between the probe and the hole in the plates was 10 mm.

From this test of force, the fracture properties (1) burst strength and (2) the displacement of the probe necessary to fracture seaweed sample was recorded and documented in the results section. The peak force is the burst strength and the displacement is the distance to burst, which is an indication of the flexibility of the seaweed.

3.1.3 Experimental Design

The design of experiment was carried out by the software: Minitab Version 17, Taghuci Design with five responses of seaweed species and five categories of time. This method ensures good performance in the product design process aiming to reduce the variability of a product (Table 1).

Table 1: Showing the Taghuci design and the responses from the experiment

Seaweed Specie	Time (m)	Test 1	Test 2	Test 3	Mean Strength (N)	Standard Deviation
Wakame	2	3.467N	2.673N	5.782N	3.974N	1.615
Wakame	5	2.201N	1.919N	1.917N	2.054N	0.164
Wakame	10	1.877N	1.908N	1.953N	1.979N	0.038
Wakame	15	1.623N	1.664N	1.447N	1.578N	0.115
Wakame	20	1.550N	1.257N	1.498N	1.444N	0.156
Kelp	2	7.325N	6.498N	8.946N	7.581N	1.245
Kelp	5	5.324N	5.121N	5.184N	5.209N	0.104
Kelp	10	6.514N	6.997N	6.780N	6.764N	0.242
Kelp	15	6.387N	5.195N	7.009N	6.209N	0.922
Kelp	20	6.487N	7.095N	6.609N	6.725N	0.322
Sugar Kelp	2	4.334N	4.978N	3.822N	4.336N	0.579
Sugar Kelp	5	2.356N	3.073N	5.101N	3.495N	1.424
Sugar Kelp	10	1.567N	3.037N	1.841N	2.124N	0.782
Sugar Kelp	15	1.367N	3.237N	1.941N	2.149N	0.958
Sugar Kelp	20	1.467N	3.039N	1.351N	1.977N	0.943
Dulse	2	3.067N	2.073N	5.282N	3.456N	1.643
Dulse	5	3.052N	2.068N	2.010N	2.379N	0.586
Dulse	10	3.041N	2.020N	2.010N	2.376N	0.592
Dulse	15	2.041N	1.902N	2.010N	1.897N	0.073
Dulse	20	2.041N	1.202N	1.101N	1.476N	0.516
Sea Spaghetti	2	4.869N	4.475N	4.689N	4.678N	0.455

Sea Spaghetti	5	2.208N	3.118N	4.276N	3.321N	0.564
Sea Spaghetti	10	3.108N	3.618N	2.999N	3.258N	0.330
Sea Spaghetti	15	3.171N	2.804N	2.982N	2.985N	0.183
Sea Spaghetti	20	2.298N	3.121N	1.916N	2.445N	0.615

Table 1 indicates quite a significant difference in measurements between the 3 tests for certain species. Wakame had a range of 2.67 to 5.78 N which could be a result of a different part of the plant and thickness which was rehydrated.

3.2 Milling Trials

Feedback from consumer research highlighted that the particle size of the seaweed is too large resulting in an increased chewy texture when rehydrated. Especially the midrib from the Wakame.

Figure 4: 50 g of seaweed inserted to different sized sieves

Varying mill sizes and heads were trialled to reduce the size of the seaweed once dried. These different sizes were sieved to measure accuracy resulting in a more consistent and acceptable product. Milling heads, A, K, and M with sizes of 2, 2.3, 3.0

and 3.8 mm with species of Wakame and Sea Spaghetti were trialled for acceptability. These different sizes and species were measured to 50 g and sieved for 5 minutes through 2 mm and 1.18 mm as shown in Figure 4.

All measurements were recorded and featured in the results section. This trial was to investigate the mill heads and the differences in sizes over 2 mm, between 1.18 mm and 2 mm and below 1.18 mm to allow for a more consistent product.

3.3 Seaweed Species used for New Product Development

Following on from the rehydration trials the seaweed species were externally tested for nutritional content (Figure 5).

Test	Unit	Atlantic Wakame (Undaria Pinnarifida)	Kelp (Laminaria Digitata)	Sugar Kelp (Saccharina Latissima)	Sea Spaghetti (Himanthalia Elongata)	Dulse (Palmaria Palmata)
Total Carbohydrates (by Difference)	g/100g	51	59.9	25.5	44.7	22.6
Total Dietary Fibre (AOAC)	g/100g	40.3	45.1	28.9	35.1	28
Fat	%	0.2	0.2	1.2	0.1	1.3
Energy	kcal	349	363	668	292	227
Energy	kJ	1503	1565	159,6	1260	948
Moisture	g/100g	12.7	7.7	9.7	9.7	6.7
Monounsaturated Fatty Acids	g/100g	0.1	<0.1	0.19	<0.1	nd
Nitrogen	%	2.5	1.26	2.5	1.7	1.9
Polyunsaturated Fatty Acids	g/100g	<0.1	<0.1	0.27	<0.1	nd
Protein	g/100g	15.6	7.9	11.7	10.6	17.2
Saturated Fatty Acids	g/100g	<0.1	0.1	0.21	<0.1	nd
Sodium	g/100g	2.36	3.59	3.56	4.97	1.65
Total Sugars	g/100g	0.3	<0.1	1.3	<0.1	<0.1

Figure 5: Nutrition results for Seaweed Species

Two seaweeds Wakame and Sea Spaghetti were selected based on availability, nutritional content and sensory results from the rehydration studies. The dried seaweeds were supplied by New Wave Foods Ltd. (Wick, Scotland), who harvest the seaweed in Wick on the north coast of Scotland. The fresh seaweed was carefully harvested by hand to ensure that they were responsibly harvested, transported to the factory where it is washed and dried at low temperatures for 24 hours to help maintain maximum nutritional content. Water activity was measured to ensure consistency of final product with efficient and flexible milling options to meet demand. In this study 6 mm and 75 mm rehydrated seaweed were used in the seaweed salads, 6 mm rehydrated seaweed in the pesto, and 1 mm dried seaweed in the seaweed crisps and seaweed crackers.

Through desktop research and site surveys, the best places for wild harvesting were identified in the Caithness region of Northern Scotland (Figure 6). These sites had expansive rocky shores, an ideal degree of exposure for seaweed, good accessibility to foreshore with a possible source of employees (Thurso and Wick). With Hams to Scarfskerry being the biggest site.

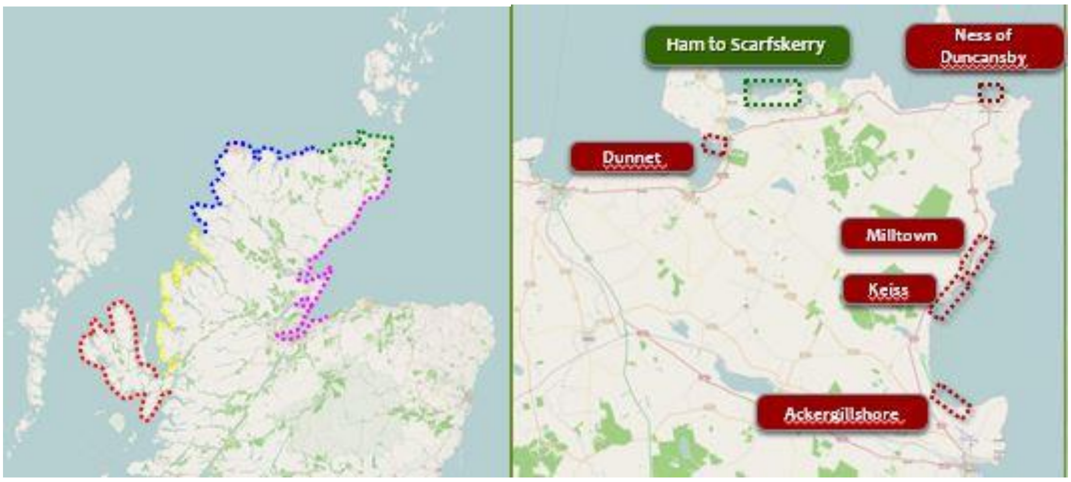


Figure 6: Map of the chosen sites to harvest the wild seaweed in the north of Scotland

All the seaweeds were harvested to Soil Association standards from harvest sites under license from the Crown Estate. The species were not harvested during reproductive periods and all species are cut by hand to allow for regrowth of the plant (Figure 7). Biomass surveys for all the sites have been conducted with continued comprehensive testing to minimise contamination and enable a sustainable harvest plan for each seaweed.

Figure 7: Seaweed hand cut to allow for regrowth

Both seaweeds were delivered to Abertay University, stored at room temperature in a dark room and used within a month for all new product development and sensory analysis.

3.4 New Product Development and Utilisation of Rehydrated Seaweed

The new product development highlighted in Figure 8, followed the food product development gated process devised by Earle and Anderson (2000).

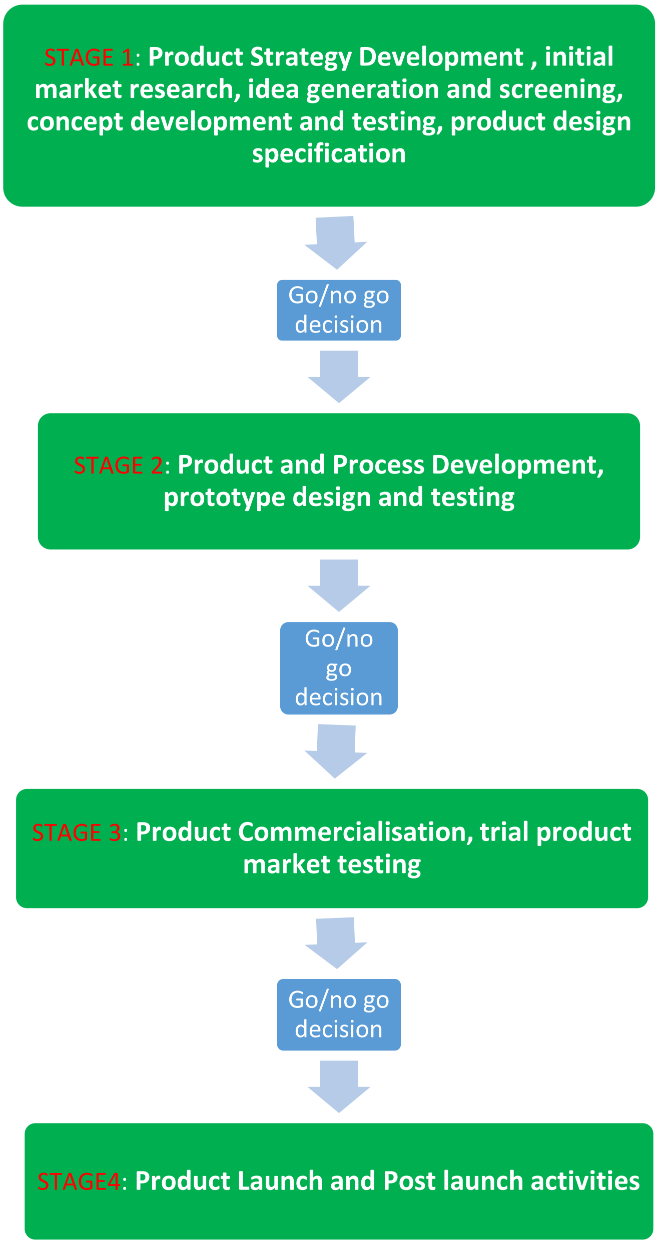


Figure 8: New product development gated process

The 4 stages represent the process for a new product to develop and either continue with launch or not depending on if each stage is successfully completed.

3.4.1 Seaweed Salads

A 75 mm cut of Wakame seaweed was initially selected for rehydration for the Seaweed salads, which would consist of 20% and 40% rehydrated seaweed salad. Research for current food trending ingredients to be added to the salad was conducted and tested with a consumer trial at Abertay. The following process of creating the salads is highlighted in Figure 9.

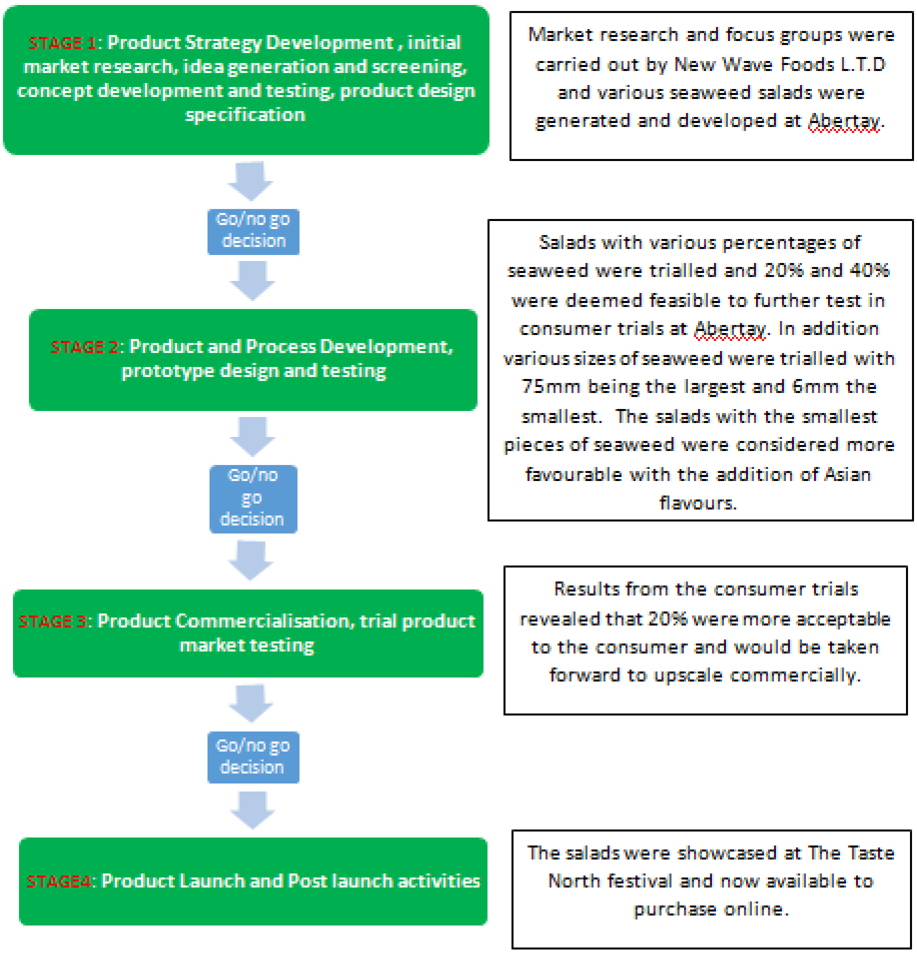


Figure 9: NPD of Seaweed Salads

The feedback given highlighted that the seaweed pieces and quantity were too large and that Asian flavours seemed to marry well with the seaweed.

Various kitchen trials concluded that a 6mm rehydrated cut of seaweed with 20% rehydrated Wakame worked best with added ingredients of a carbohydrate such as noodles and brown rice with various flavours to balance well with the seaweed.

3.4.2 Seaweed Pesto

Benchmarked on seaweed products from The Pembrokeshire Beach Food Company and The Cornish Seaweed Company a pesto was developed with fresh, frozen and reduced fat versions. The dried *Himathalia Elongate* (Sea Spaghetti) was placed in a bowl with 40ml of water. After 15 minutes the seaweed was fully re-hydrated. The hydrated seaweed was placed in a food processor along with the pine nuts, lemon juice, various oil quantities, garlic paste and cheese. All ingredients were blended together until the desired consistency was reached. A consumer trial was then conducted in Abertay's consumer labs to gain an understanding of the consumer preference of each pesto.

3.5 New Product Development and Utilisation of Dried Seaweed

3.5.1 Preparation of Seaweed Crisps

According to Kayacier *et al.,* (2014), the snack food market is worth approximately £22 - £26 billion annually in the world. The consumption of snacks is continuously increasing in many countries and considered a large part of the human diet. (Taijner-Czopek and Rytel, 2010). The most popular snack products are crisps, which were to be developed in this study with the addition of dried seaweed.

The aim was that this new product would contain between 30 and 40 % dried 1 mm seaweed with 70 % or 60 % flour mixture. These would be benchmarked on the Halo seaweed crisp brand and contain gluten free flours such as rice flour and the possibility of Tapioca and Soy flour. Including a constant measurement of oil, water and sugar. Small-scale kitchen recipes were produced using a Lillo due – Bottene (Italy) pasta machine with a mixer shaft and auger and a hold capacity of 1,400 kg to mix and extrude the various crisp mixtures. Die heads were used to shape the crisp mixture before it was baked for 10 minutes at 160 ºC. The following process of creating the crisps is highlighted in Figure 10.

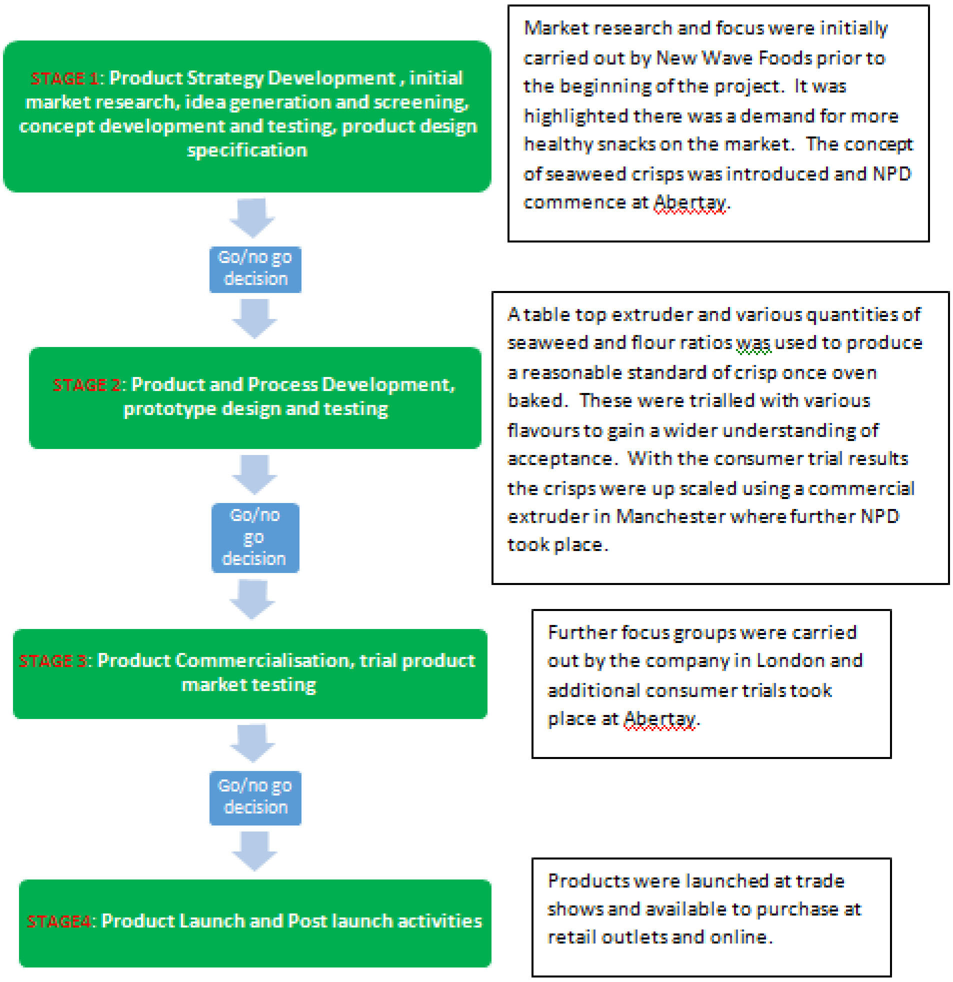


Figure 10: NPD of Seaweed Crisps

A Continua 37, Werner Pfleiderer Ltd. twin-screwed co-rotating cooker extruder was then used to carry out pilot scale trials at Manchester Metropolitan University with the recipes from the small kitchen trials. Various dial settings, screw speeds, temperatures and dies were used with the mixture to produce the most accepted crisp product based on small consumer trails conducted at Abertay

3.6 Consumer Trials

The consumer trials took place in the Abertay sensory booths ISO9001 with 58 participants testing the salads, 60 testing the pesto, 59 for the seaweed crisps and 15 participants using TDS for the seaweed crackers. Samples were given at room temperature and positioned in transparent plastic cups (89.0 mm x 56.0 mm), labelled with random 3-digit codes which varied per panellist.

Samples were arranged according to a balanced serving order randomised within each serving set to reduce physiological and psychological effects including contrast, convergence and carry over effect (Lawless and Heymann, 2010). Any first order bias was removed as consumers may consistently score the first product higher or lower than other products regardless of what product is being evaluated (Pilgrim and Peryman, 1996).

Water was given to cleanse the palette between each sample and participants were asked to rate the appearance, texture, aroma and overall acceptance of each sample using the traditional 9-point hedonic scale (Peryam and Pilgrim 1957). The sensory attributes important for each product category in terms of consumer acceptability are highlighted below (Table 2).

Table 2: Sensory attributes important for consumer acceptability

Product	Sensory Attributes for Acceptability
Salads	Not chewy, no strong fishy aroma, colourful and fresh appearance
Crisps	Crispy, not soft or gritty, no strong fishy aroma
Pesto	Not chewy, not oily, no strong fishy aroma
Crackers	Crunchy, not soft or gritty, no strong fishy aroma

The 9-point hedonic scale has been adopted by researchers in the chemical senses and became the dominant tool for measuring hedonic perception (Lim, Wood and Green, 2009).

3.7 Preparation of the Seaweed Crackers for TDS

According to Kadam and Prabhasankar (2010) by researching the targeted population, bakery products are deemed the best source of incorporating functional ingredients such as seaweed as they are widely consumed all over the world.

Using TDS for the seaweed crackers is a novel area as no other studies appear to have used it as a consumer sensory tool with seaweed. This will enable a deeper understanding of what attributes are dominant whilst consuming a seaweed product which may affect the acceptability of it.

Preliminary experiments were conducted to establish appropriate flour varieties and maximum levels of dried seaweed that could be added to a cracker bread in terms of stability of texture and flavour. The cracker bread was too tough with concentrations higher than 20 % so this limit was deemed suitable by small kitchen panel testing.

A factorial design with three replicates was set up established using a statistical software package Minitab version 17, to incorporate two different seaweeds into a standard cracker mixture. The wholemeal flour constituent was replaced with the following percentages of seaweed: 5, 10, 15 and 20. A control with no seaweed was included and 30 runs were generated (Table 3). The constant ingredients in the recipe were water, oil and sugar.

Table 3: Factorial design with 30 runs

Seaweed Concentration (%)	Wholemeal Flour (%)	Seaweed Species
0.05	0.95	Wakame
0.10	0.90	Wakame
0.00	1.00	Control
0.15	0.85	Wakame
0.00	1.00	Control
0.10	0.90	Sea Spaghetti
0.20	0.80	Sea Spaghetti
0.05	0.95	Sea Spaghetti
0.20	0.80	Wakame
0.10	0.90	Wakame
0.20	0.80	Wakame
0.15	0.85	Wakame
0.20	0.80	Sea Spaghetti
0.00	1.00	Control
0.00	1.00	Control
0.10	0.90	Sea Spaghetti
0.00	1.00	Control
0.20	0.80	Sea Spaghetti
0.05	0.95	Sea Spaghetti
0.05	0.95	Sea Spaghetti
0.10	0.90	Wakame
0.05	0.95	Wakame
0.00	1.00	Control
0.15	0.85	Sea Spaghetti
0.15	0.85	Sea Spaghetti
0.15	0.85	Wakame
0.10	0.90	Sea Spaghetti
0.05	0.95	Wakame
0.15	0.85	Sea Spaghetti
0.20	0.80	Wakame

The ingredients for the crackers were measured out and mixed in a Kenwood Chef Titanium XL KVL8300S, rolled out, cut to 2 mm thick squares, and placed on a baking sheet in an oven for 14 minutes at 180 ^{0}C. The seaweed crackers were then cooled and placed in airtight containers until required and used within 2 days.

3.7.1 Panellists selection for TDS sessions

The panellists were selected using the following inclusion criteria: an interest in healthy eating; trying new innovative food products; aged between 20 and 40 years old; and predominantly female. Testing was conducted at Abertay's Food Innovation sensory consumer labs. Fifteen panellists (Pineau, 2009) aged between 21 and 40 were selected. The panels consisted of food and consumer studies students and academics from Abertay's Food and Drink division.

Panellists were also non-smokers; had good oral health and overall general health; could distinguish between sensory attributes from the given questionnaire; they all spoke fluent English; and used computers frequently. Research Ethics was approved by the School of Science, Engineering and Technology Research Ethics Committee at Abertay University. All panellists were given information on the outline and aim of the study. They gave informed consent and were given the opportunity to drop out at any time.

3.7.2 Sensory Attribute Generation for TDS

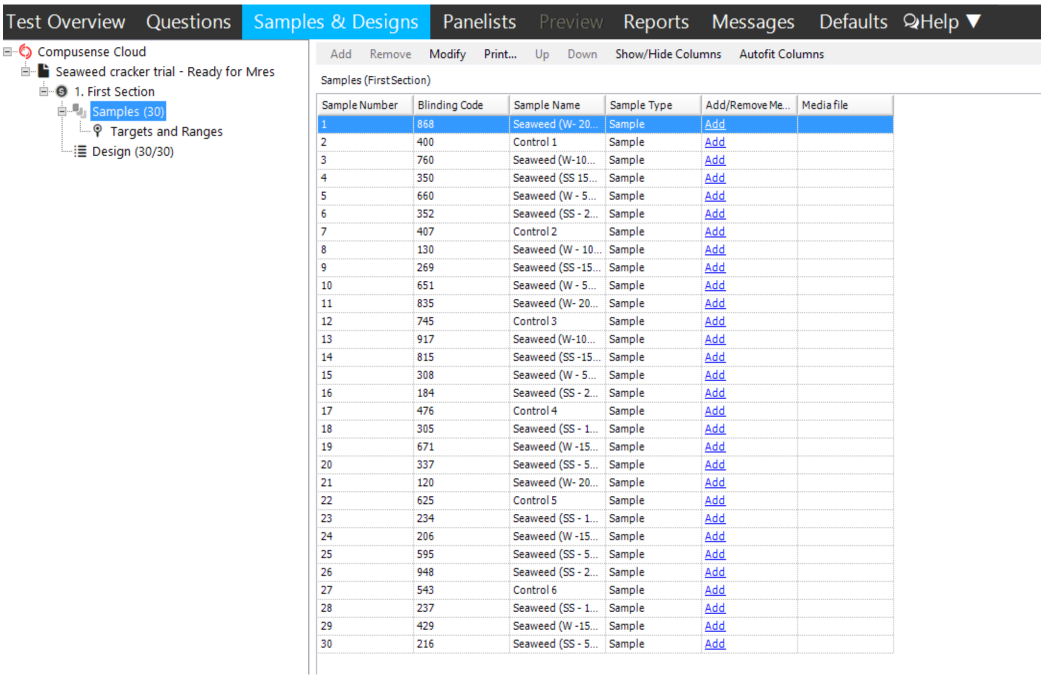
Comments and feedback from the consumer trails were used to construct the attribute list for the seaweed crackers. In addition, ten panellists from the consumer panels were requested to consume approximately half of each cracker sample. Sensory attributes were discussed and created describing each sample with a recommended list of a maximum of 10 attributes (Pineau, 2012). The attribute list has a mixture of types such as texture and taste included with the order balanced between panellists to avoid position bias. The panellists who created these sensory attributes were not permitted to partake in the study.

3.7.3 Warm-up and Preparation Process

Limited training is required to use TDS if the attributes given are straightforward enough to understand. Products overall liking can be easily measured, and sensory attributes can modulate the hedonic appreciation and/or depreciation during consumption (Labbe, 1999).Panellists were given a 5-minute warm-up period before each session (5 in total with 6 samples per session). This was to give a further explanation of the concept of TDS and the sensory attributes used. Questions were welcomed at any stage for clarification.

3.7.4 Experimental Process

Each panellist attended five sessions (for TDS) with 6 samples per session on separate days. Each session lasted approximately 20 minutes and there was a 30 second break between samples. All samples were arranged in randomised balanced order generated by the Compusense software as seen in Figure 11.



Sample Number	Blinding Code	Sample Name	Sample Type	Add/Remove Me...	Media file
1	868	Seaweed (W- 20...	Sample	Add	
2	400	Control 1	Sample	Add	
3	760	Seaweed (W-10...	Sample	Add	
4	350	Seaweed (SS 15...	Sample	Add	
5	660	Seaweed (W - 5...	Sample	Add	
6	352	Seaweed (SS - 2...	Sample	Add	
7	407	Control 2	Sample	Add	
8	130	Seaweed (W - 10...	Sample	Add	
9	269	Seaweed (SS -15...	Sample	Add	
10	651	Seaweed (W - 5...	Sample	Add	
11	835	Seaweed (W- 20...	Sample	Add	
12	745	Control 3	Sample	Add	
13	917	Seaweed (W-10...	Sample	Add	
14	815	Seaweed (SS -15...	Sample	Add	
15	308	Seaweed (W - 5...	Sample	Add	
16	184	Seaweed (SS - 2...	Sample	Add	
17	476	Control 4	Sample	Add	
18	305	Seaweed (SS - 1...	Sample	Add	
19	671	Seaweed (W -15...	Sample	Add	
20	337	Seaweed (SS - 5...	Sample	Add	
21	120	Seaweed (W- 20...	Sample	Add	
22	625	Control 5	Sample	Add	
23	234	Seaweed (SS - 1...	Sample	Add	
24	206	Seaweed (W -15...	Sample	Add	
25	595	Seaweed (SS - 5...	Sample	Add	
26	948	Seaweed (SS - 2...	Sample	Add	
27	543	Control 6	Sample	Add	
28	237	Seaweed (SS - 1...	Sample	Add	
29	429	Seaweed (W -15...	Sample	Add	
30	216	Seaweed (SS - 5...	Sample	Add	

Figure 11: Randomised Blinding codes generated by Compusense software

Data was collected using Compusense software following a similar protocol with amendments outlined by Vázquez-Araújo *et al.,* (2013).Categorical liking of overall acceptability of each seaweed cracker using a 9-point hedonic scale was accumulated after each TDS sequence when panellists selected the 'stop' button and before testing the next cracker sample. Panellist were seated at individual booths controlled by green lighting to blend in with the sample, so no bias was apparent with appearance attributes (Figure 12).

Figure 12: Panellist at individual booth tasting sample

Panellists were instructed to place the sample in their mouth then immediately press the 'Green Start' button. The chosen attributes were presented on screen (Figure 13) and the dominant attributes were selected when perceived.

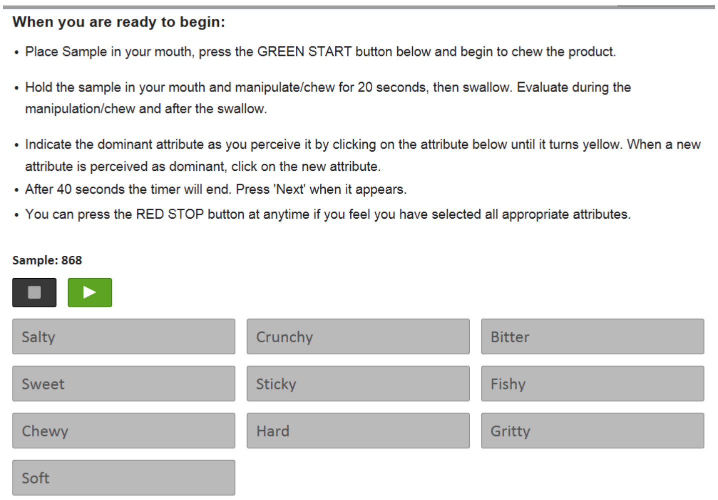


Figure 13: Selection of attributes for each panellist to choose when dominant

There was a reminder before consumption to check all sample codes matched the code onscreen to ensure the correct seaweed cracker was sampled. Panellists were notified that not all attributes were required to be selected and the same one could be chosen several times. They were given 40 seconds to choose the attributes, and if swallowed before then the ‘Red Stop’ button could be pressed.

3.8 Method Justification

A consumer trial was conducted to measure acceptance of the seaweed salads, seaweed crisps and seaweed pesto’s with the intention of acquiring 60 participants. An increase in sample size was considered to enable parametric tests but this was not possible due to time constraints.

This consumer trial method of evaluation was to save time, training and commitment as opposed to using a trained sensory panel. A sensory panel would be more appropriate for repeated assessments, than directly assessing acceptability. (Hough *et al.,* 2002).

Participants were informed of the seaweed product trials by email and posters displayed around the university to advertise the dates the trials were to be conducted.

TDS was chosen over TCATA because we wanted to measure just one attribute that overpowered the product due to it being the seaweed. A significant difference between these two methods is concept of dominance, being fundamental to TDS. (Ares *et al*., 2015). We already knew from the consumer trials that flavour and texture may be an issue with consumers.

3.9 Data Analysis

3.9.1 Generation of Response Rate and Significance Line TDS Graphs

The response rate was determined by the selected attributes and the time that participants responded in, within the 40 seconds. Labbe *et al.* (2009) states a "significance level" line is typically included in every individual dominance rate graph. This level is defined as the highest limit of the confidence interval for dominance rate expected (Pineau *et al.,* 2009). Dominance rate at 10 % significance was recorded in using the calculation:

$$\text{Dominance Rate} = 0.1 + (1.282*(\sqrt{}\ (0.09/\text{no. of participants}))$$

The higher the attributes dominance rate suggests a higher agreement among participants towards the attribute at that time.

3.9.2 Statistical Analysis

Statistical analysis (IBM SPSS Statistics v22) was performed to consider main effects and interactions for seaweed type and seaweed concentration ($p<0.05$) using a two-way ANOVA incorporating the general linear model. In addition, for the results of the milling of the seaweed a normality test was carried out to discover if the data was normally distributed. The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all milling factors. Statistical analyses were carried out using a Mann-Whitney Test to determine any significant differences in species being sieved or the mill head used.

A normality test was carried out for the 40% and 20% seaweed salad samples, the seaweed pesto and seaweed crisps. The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all consumer testing.

Each medium for every attribute were analysed using a K related Friedman test with data shown to be significantly different. Each difference in attribute was further analysed against each other by using a paired Wilcoxon test to further explore significant differences between samples.

4. Results

4.1 Rehydration Results

Figure 19 represents the mean force required to break/puncture the rehydrated seaweed samples over time. Five seaweeds, Wakame (A), Kelp (B), Sugar Kelp (C), Dulse (D) and Sea Spaghetti (E) were selected and were rehydrated in deionised water and measured at five time intervals (2, 5, 10, 15 and 20 minutes).

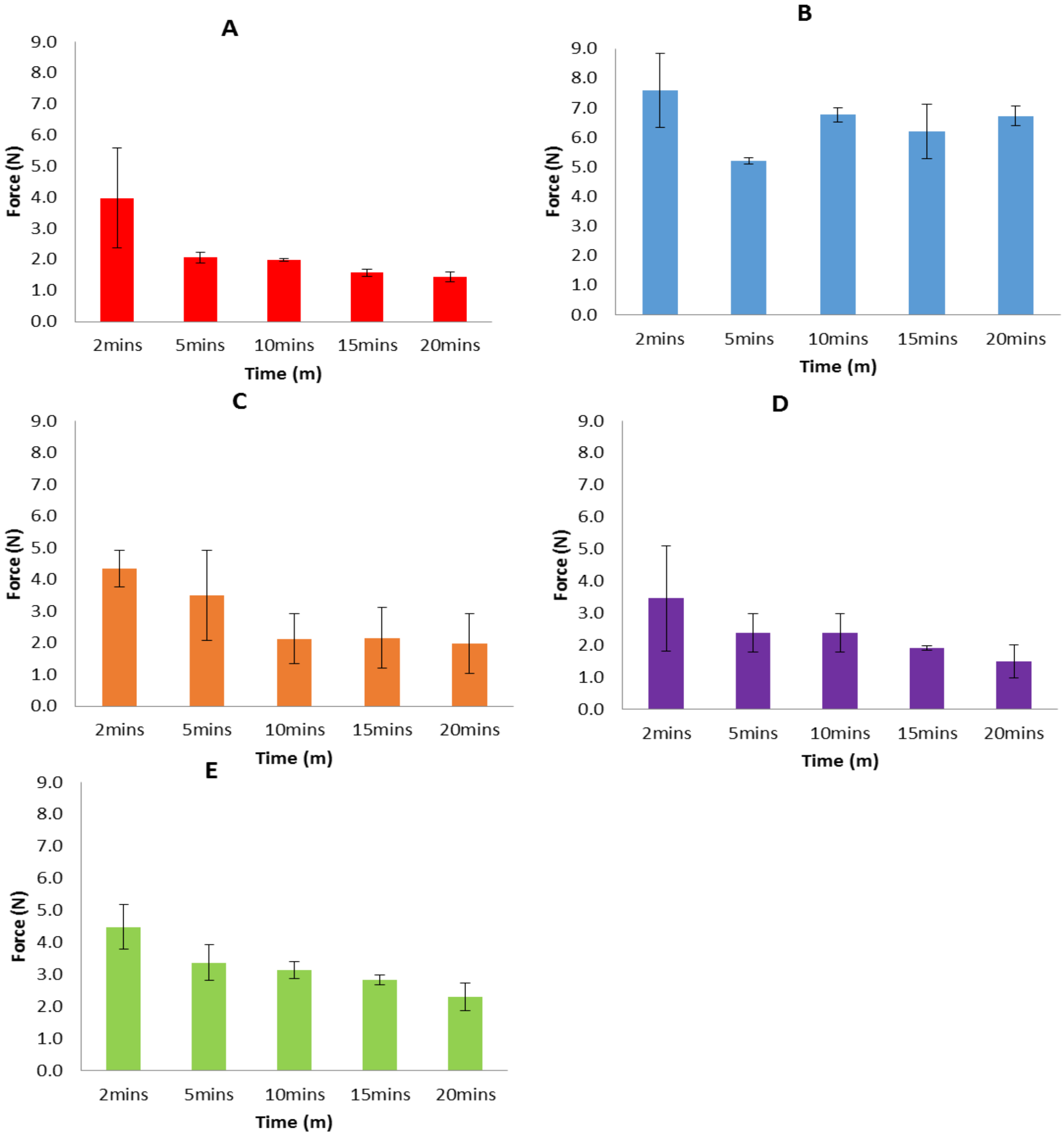


Figure 14: Burst strength of rehydrated seaweeds

Figure 14 shows that Wakame (A), Dulse (D) did not require as much strength to burst through the sample when compared with Kelp (B), Sugar Kelp (C) or Sea Spaghetti (E). Figure 14 A shows that the Wakame puncture force was 4.0 N after two minutes of rehydration, however after 5 minutes this reduced to 2.0 N. From 10-20 minutes no big differences were observed for this seaweed, therefore 5 minutes was the maximum rehydration for Wakame.

Figure 14 B indicates the Kelp samples had a higher burst strength force than the rest of the seaweed species (5-7.8 N). During 2minutes the burst force required was at its highest 7.8 N. By 5 minutes, the Kelp softened with reduced force strength enabling a softer texture. However, it became tougher and increased in force by 10 minutes where it had levelled off. The data from Figure 14 C shows the varying results for Sugar Kelp with a higher puncture force after 2 minutes rehydration (4.3 N). The Sugar Kelp sample had softened slightly but remained tough by 5 minutes (3.4 N). The puncture force reduces to 2.1 N by 10 minutes and levelled off by 20 minutes. Therefore, 10 minutes would be a maximum time for rehydration.

Figure 14 D highlights the decline in force strength with Dulse over time with it shown to be the softer seaweed species after rehydration. The puncture force at 2 minutes was 3.4 N, which became softer at 5 minutes (2.3 N) with not much difference in force by 10 minutes rehydration. It was almost too soft and unpalatable by 15 minutes (1.89N) therefore 5 minutes would be the maximum rehydration time for Dulse. The data from Figure 14 E shows that the Sea Spaghetti puncture force was 4.6 N after two minutes of rehydration, however after 5 minutes this reduced to 3.3 N. From 5 to 15 minutes no big differences were observed for this seaweed, therefore 5 minutes was the maximum rehydration for Sea Spaghetti.

After 5 minutes, the seaweeds overall texture softened with a gradual reduction in the force required to puncture the samples and this continued over 20 minutes where a decrease in burst strength was observed. The results showed that the maximum appropriate time for rehydration for each seaweed was: 5 minutes for Wakame, Kelp and Sugar Kelp and 10 minutes for Dulse and Sea Spaghetti.

The aim of this investigation was to determine whether species of seaweed (n=5) and time of rehydration (n=5) influenced the force required to puncture the seaweed. These findings were confirmed using a two-way ANOVA where no significant differences observed for species of seaweed and time of rehydration ($F (16, 50) = 1.198$; $p=0.302$), however time of rehydration and species of seaweed were significantly different independently, ($F=15.717$; $p<0.001$; and $F=76.780$; $p<0.001$, respectively). Post hoc analysis (Tukey) revealed that 2 minutes was significantly different compared to all other times ($p<0.001$), whilst all other times were not significant ($p>0.05$). Regarding species a post hoc analysis (Tukey) revealed that Kelp was the significant different species ($p<0.001$) than all other species ($p>0.05$), no other significant differences were observed. The ANOVA method is sufficiently robust to cope with small deviations from the assumptions and is more powerful and preferable to equivalent non-parametric tests.

Throughout the rehydration process, each seaweed species was weighed at each time interval, which was recorded in Table 4.

Table 4: Water holding capacity of species of seaweeds and rehydration time

	Fresh water (100ml)		
Seaweed Species	Time (m)	Weight (g)	% Increase of Weight
Wakame	0	1.00	0%
	2	2.88	188%
	5	3.92	292%
	10	4.75	375%
	15	5.26	426%
	20	5.76	476%
Kelp	0	1.00	0%
	2	1.81	81%
	5	2.28	128%
	10	2.22	122%
	15	4.52	352%
	20	4.88	388%
Sugar Kelp	0	1.00	0%
	2	3.45	245%
	5	4.37	337%
	10	5.14	414%
	15	5.69	469%
	20	5.97	497%
Dulse	0	1.00	0%
	2	2.98	198%
	5	3.10	210%
	10	3.28	228%
	15	3.31	231%
	20	3.33	233%
Sea Spaghetti	0	1.00	0%
	2	1.46	46%
	5	1.82	82%
	10	2.53	152%
	15	2.89	189%
	20	3.32	232%

Wakame and Sugar Kelp had the highest increase in weight gain over the 20 minutes of rehydration (476 %, 497 % respectively). Sea Spaghetti and Dulse had the lowest weight gain over the 20 minutes of rehydration (232 %, 233 % respectively).

Interestingly, after 2 minutes Sugar Kelp had the highest increase of weight gain at 245 %, then Dulse at 198 %, whereas, Sea Spaghetti had the lowest at 46 %. Kelp had a gradually increase in weight gain up until 10 minutes then a big increase of 230 % up to 15 minutes.

4.2 Milling Results

At the start of the trial, the seaweed was accurately weighed to 50.0±0.1 g and placed in the sieve for 5 minutes; each species was completed in triplicate. The mean weight (g) of the overall amount of seaweed gathered in each sieve are presented in Table 5.

Table 5: Data recorded during the sieving process

Species	Code	Size of Mill (mm)	Head	Over 2mm Sieve (g)	Between 2mm & 1.18mm Sieve (g)	Below 1.18mm (g)
Wakame	3M030120	3	M	1.16±0.09	12.46±1.80	36.38±1.71
Wakame	3K030120	3	K	8.26±1.11	16.04±0.056	25.7±0.25
Wakame	3K030090U	2.3	K	4.98±1.15	20.83±1.42	24.19±1.14
Wakame	3A090090	2.3	A	3.23±0.05	22.23±1.08	24.54±1.03
Sea Spaghetti	3M030120	3	M	1.21g±0.04	16.63±0.50	32.16±0.50
Sea Spaghetti	3K030120	3	K	6.95±0.22	23.94±0.60	19.11±0.38
Sea Spaghetti	3K030090U	2.3	K	3.74±1.20	21.87±1.62	24.39±1.04
Sea Spaghetti	3A090090	2.3	A	3.8±0.18	24.60±0.98	21.60±0.90

Table 5 shows that overall; the M head was the most consistent in size when comparing the dried and rehydrated seaweed samples. The M head reduced the size of the midrib section of Wakame seaweed when compared to the A and K heads which had a higher percentage left in the sieve over 2 mm. It was felt that seaweed pieces below 3 mm were too small and would be lost in the salads and would therefore not be used. It was observed that once sieving was completed there was a large portion of dried seaweed under 1.18 mm in size with all mill heads.

The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all milling factors. Statistical analyses were carried out using a Mann-Whitney Test to determine any significant differences in species being sieved or the mill head used.

There were no significant differences between Wakame and Sea Spaghetti being sieved ($Z= 0.014$, $p = 0.989$), or for the mill size ($Z= 0.0160$, $p = 0.873$). Overall, the M head was the most consistent in size when comparing the dried and rehydrated seaweed samples.

4.3 Seaweed Salads with Rehydrated Seaweed

Based upon the results obtained from the sieving trials, 6 mm thick seaweed pieces were used in the production of seaweed salads. Three flavour combinations were selected, and two seaweed percentages were evaluated by consumers.

Figure 15 shows the differences in seaweed salads, where 20 % Wakame seaweed soy mirin and ginger showed the highest consumer acceptability (6.79) compared with the same flavour but with 40 % seaweed (5.12). The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all consumer testing.

The median and percentiles were further investigated (40% and 20% seaweed salads) and are represented as median (IQR 25% and 75% percentile). For this consumer analysis 58 participants were evaluated, Female = 35, Male = 23.

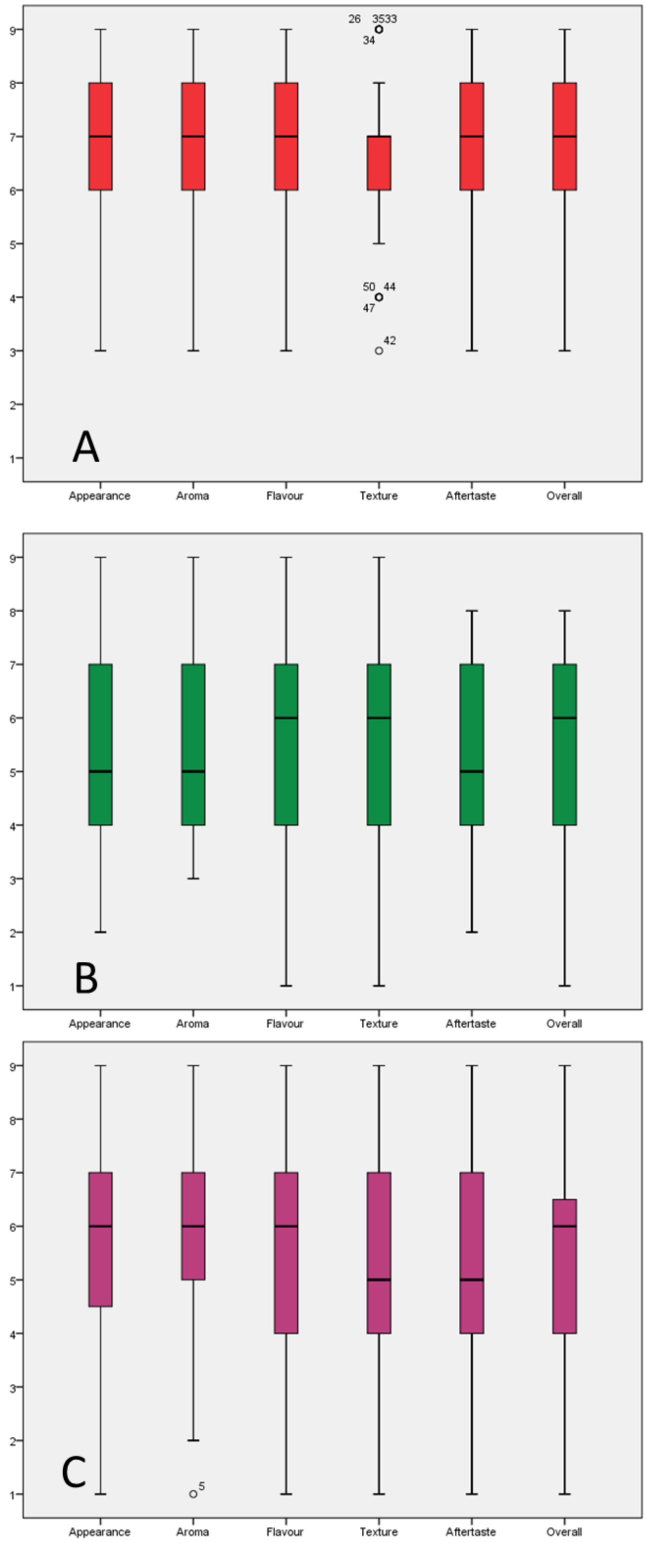


Figure 15 Boxplots for seaweed salad, A) 20% Soy, Mirin & Ginger Salad, B) 20% Teriyaki Salad, C) 20% Lime, Chilli & Coconut Salad.

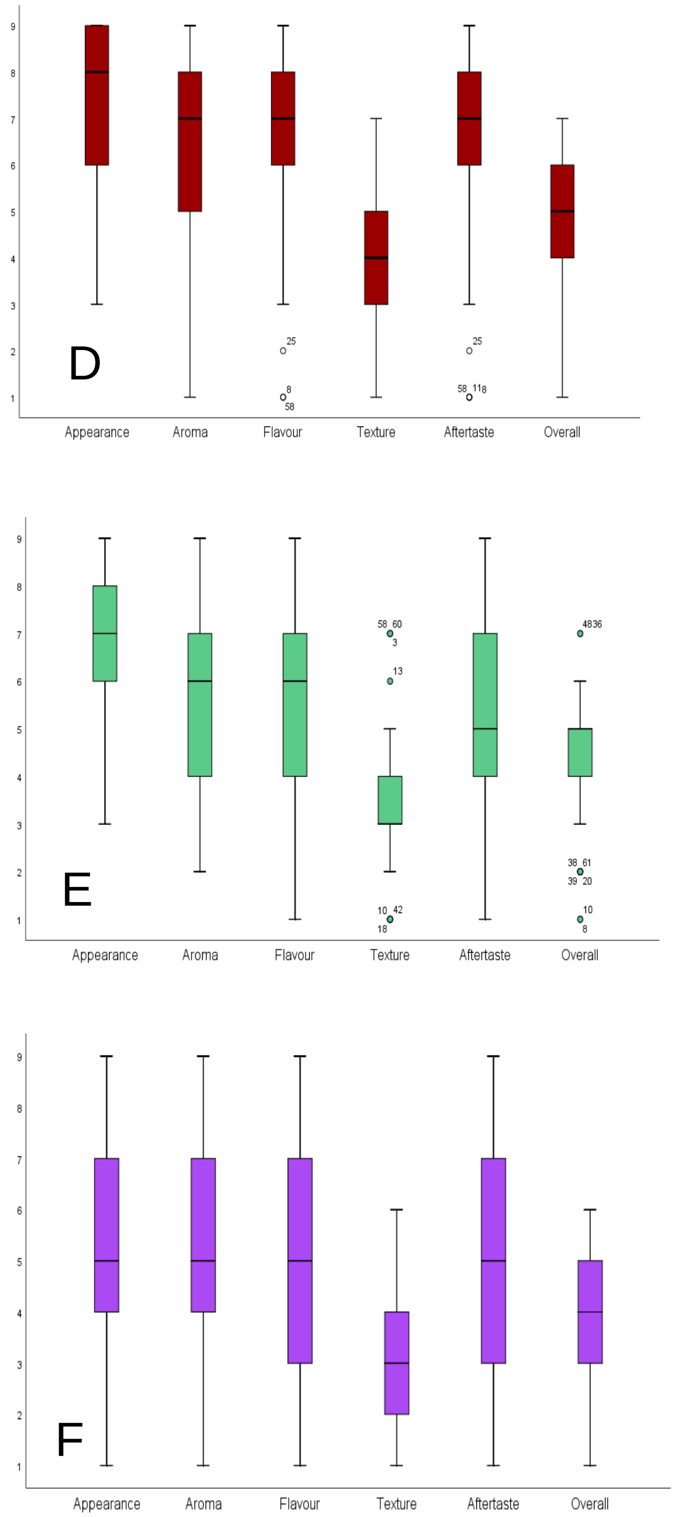


Figure 16 Box plots for seaweed salad D) 40% Soy, Mirin & Ginger Salad, E) 40% Teriyaki Salad and F) 40% Lime, Chilli & Coconut Salad

The boxplot results for each salad are based on consumer acceptance on a 9 point hedonic scale.

Interestingly, the soy and teriyaki salads appearances, aroma and flavour were preferred by the consumer (Figure 16) (6.0-8.0). The soy flavoured salad score 7.0 for aftertaste, however each salad showed a very low acceptability on texture (3.0-4.0), and this could have reduced the overall acceptability of the salads. The texture between all salads differed in acceptability and were rated considerably lower in the 40% seaweed salads (4.0, 3.0, 3.0) than the 20% seaweed salads (7.0, 6.0, 5.0).

Lime, chilli and coconut at 40 % seaweed scored a lower rating than other products within this consumer testing. In the 20 % seaweed salad lime, chilli and coconut scoring was consistently higher than the 40 % (ranging from 5.0-6.0for the 20 % seaweed salad and 3.0-5.0 for the 40 % seaweed salad).

Each median for every attribute of the 40 and 20 % seaweed salads were analysed using a K related Friedman test with data shown to be significantly different. Each difference in attribute was further analysed against each other by using a paired Wilcoxon test to further explore significant differences between samples.

There was a statistically difference in consumer acceptance towards appearance depending on what seaweed salad (Figure 16) sample was tested, X^2 (2) = 43.518, $p<0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p< 0.01$. Median (IQR) perceived appearance levels for the soy, mirin & ginger salad, teriyaki salad, lime, chilli &coconut salad were 8.0 (6.0,9.0), 7.0 (5.5,8.0) and 5.0 (4.0,7.0), respectively.

There were significant differences between the 40% seaweed salads (Figure 16)soy, mirin & ginger salad - lime, chilli & coconut salad (Z= -5.464, $p<0.001$), teriyaki salad, lime, chilli &coconut salad (Z=-3.587 p<0.001). There was a statistical difference in consumer acceptance towards flavour depending on what seaweed salad sample was tested, X^2 (2) = 27.930, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at *p*< 0.01. Median (IQR) perceived flavour levels for the soy, mirin & ginger salad, teriyaki salad, lime, chilli & coconut salad were 7.0 (6.0,8.0), 6.0 (4.0,7.75) and 5.0 (3.0,7.0), respectively. There were significant differences between the soy, mirin & ginger salad, lime, chilli & coconut salad (Z=-4.312, p<0.001), soy, mirin & ginger salad - teriyaki salad (Z=--3.224, p = 0.001).

There was a statistically difference in consumer acceptance towards aftertaste depending on what seaweed salad sample was tested, X^2 (2) = 27.508, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at *p*< 0.01. Median (IQR) perceived aftertaste levels for the soy, mirin & ginger salad, teriyaki salad, lime, chilli & coconut salad were 7.0 (6.0,8.0), 5.0 (4.0,7.0) and 5.0 (3.0,7.0), respectively.

There were significant differences between the soy, mirin & ginger salad, teriyaki salad (Z=-3.389, p = 0.001), soy, mirin & ginger salad - lime, chilli & coconut salad (Z=-4.221, p = 0.001).

There was a statistically difference in consumer acceptance towards overall acceptability depending on what seaweed salad sample was tested, X^2 (2) = 27.420, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at *p*< 0.01. Median (IQR) perceived overall acceptability levels for the soy, mirin & ginger salad, teriyaki salad, lime, chilli & coconut salad were 5.0 (4.0,6.0), 5.0 (4.0,5.0) and 4.0 (3.0,5.0), respectively. There were significant differences between the soy, mirin & ginger salad - teriyaki salad (Z=-2.764, p = 0.006), soy, mirin & ginger salad - lime, chilli & coconut salad (Z=--4.842, p<0.001).

Further statistical analysis was conducted using a Wilcoxon signed-rank tests with a Bonferroni correction applied, resulting in a significance level set at *p*< 0.01. This was to determine any significant differences with the appearance of 40% soy, mirin &

ginger salad seaweed salad against the 20% soy, mirin & ginger salad seaweed salad. There were no significant differences with appearance ($Z=-1.912$, $p = 0.056$), aroma ($Z=-0.846$, $p = 0.397$), flavour ($Z=--1.215$, $p = 0.224$) and aftertaste ($Z=--1.066$, $p = 0.286$).

There were however significant differences between the 40% soy, mirin & ginger salad seaweed salad against the 20% soy, mirin & ginger salad for texture (($Z=5282$, $p<0.001$) and overall acceptance ($Z=4.266$, $p<0.001$).

4.4 Seaweed Pesto Products

Using 6 mm rehydrated Sea Spaghetti for a seaweed pesto; four samples were produced with varying levels of fat content. Figure 17 shows the overall acceptability of a consumer trial conducted with the rehydrated seaweed in the final product.

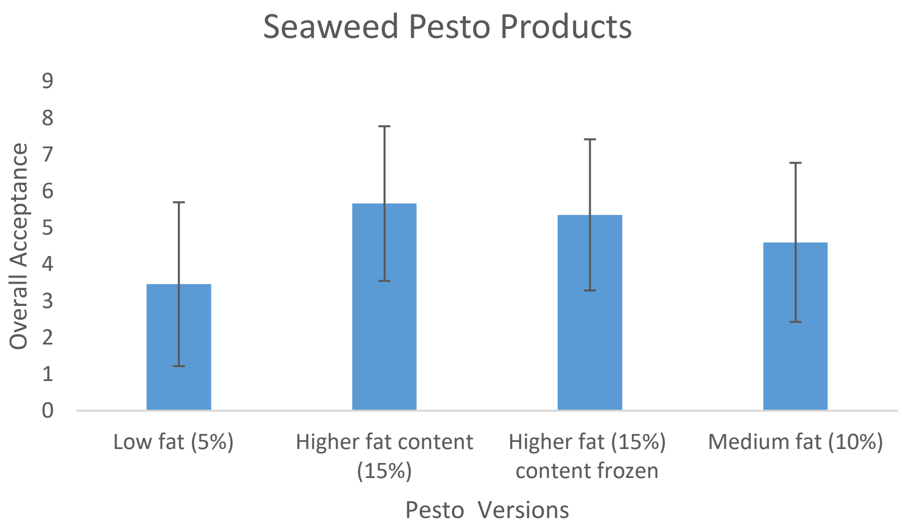


Figure 17: Seaweed pesto overall acceptance of seaweed pesto products

Figure 17 shows the differences in mean values of the created flavours of seaweed pesto's, where the higher fat content version showed the highest consumer acceptability (5.66) closely followed by the frozen higher fat version (5.35). The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all consumer testing.

The median and percentiles were further investigated, for this consumer analysis 60 participants were evaluated, Female = 38, Male = 22.

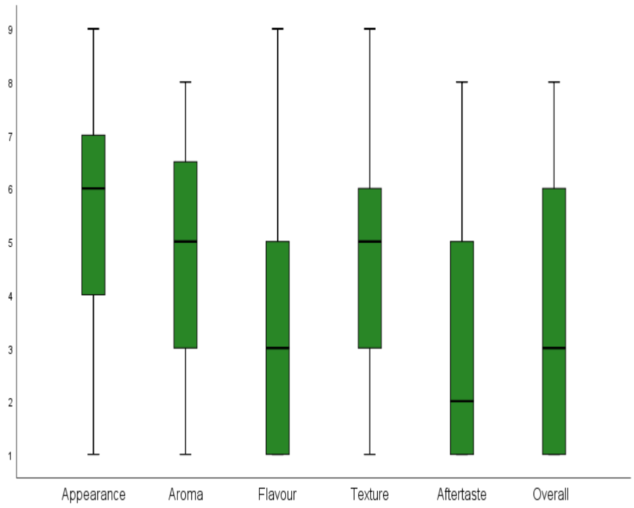


Figure 18: Boxplot results of Seaweed Pesto

The high fat seaweed pesto appearance, aroma, flavour, texture and overall impression was preferred by the consumer (6.0-7.0) and for aftertaste the high fat, high fat frozen and medium fat were similar (5,0). The aftertaste and flavour of the low-fat pesto was rated extremely low (2.0, 3.0) respectively, which may have reduced the overall acceptability. There was only a slight difference between the high fat and high fat frozen pesto samples with the flavour (7.0, 6.0). The appearance of the medium fat frozen pesto was surprisingly low (4.0) which may have also reduced the overall acceptability.

Each attribute for each sample were compared and analysed using a K related Friedman test with data proven significantly different. Each noticeable difference in attribute were further analysed using a 2 paired Wilcoxon test data and shown to be significantly different.

There was a statistical difference in consumer acceptance towards appearance depending on what seaweed pesto sample was tested, X^2 (3) = 48.465, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at p<0.01. Median (IQR) perceived appearance levels for the Low Fat, High Fat, High Fat Frozen, Medium Fat were 6.0 (4.0,7.0), 6.0 (5.0,7.0), 6.0 (4.25,7.0) and 4.0 (2.0,5.0), respectively.

There were significant differences between the Low Fat – Med Fat (Z= -4.438, p<0.001), the High Fat – Med Fat (Z= -5.412, p<0.001), or between High Fat Frozen – Med Fat (Z= -5.699, p<0.001).

There was a statistical difference in consumer acceptance towards aroma depending on what seaweed pesto sample was tested, X^2 (3) = 39.684, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p< 0.01$ Median (IQR) perceived aroma levels for the Low Fat, High Fat, High Fat Frozen, Medium Fat were 5.0 (3.0,6.75), 7.0 (5.25,8.0), 7.0 (5.25,7.0) and 6.0 (4.0,7.0) respectively.

There were significant differences between the Low-Fat Seaweed Pesto - High Fat Seaweed Pesto (Z= -4.543, p<0.001), Low Fat Seaweed Pesto - High Fat Frozen Seaweed Pesto (Z= -4.145, p<0.001), Medium Fat Seaweed Pesto - High Fat Seaweed Pesto (Z= -4.615, p<0.001), or between Medium Fat Seaweed Pesto - High Fat Frozen Seaweed Pesto (Z= -3.573, p<0.001). There was a statistical difference in consumer acceptance towards flavour depending on what seaweed pesto sample was tested, X^2 (3) = 54.540, p<0.001.

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p< 0.01$ Median (IQR) perceived flavour levels for the Low Fat, High Fat, High Fat Frozen, Medium Fat were 3.0 (1.0, 5.0), 7.0 (5.0, 8.0), 6.0 (4.25, 7.0) and 5.0 (3.0, 7.0) respectively.

There were significant differences between the Low-Fat Seaweed Pesto and High Fat Seaweed Pesto (Z= -5.832, p<0.001), Low Fat Seaweed Pesto and High Fat Frozen Seaweed Pesto (Z= -4.788, p<0.001). For the Low-Fat Seaweed Pesto and Medium Fat Seaweed Pesto (Z= -3.210, p<0.001), Medium Fat Seaweed Pesto and High Fat Seaweed Pesto (Z= -2.085, p<0.001), or between Medium Fat Seaweed Pesto and

High Fat Frozen Seaweed Pesto (Z= -2.623, p<0.001). No further statistical analysis was required with the texture attribute as the mean ranking had no strong variations.

There was a statistical difference in consumer acceptance towards aftertaste depending on what seaweed pesto sample was tested, X^2 (3) = 31.674, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at p< 0.17 Median (IQR) perceived aftertaste levels for the Low Fat, High Fat, High Fat Frozen, Medium Fat were 2.0 (1.0, 5.0), 5.0 (4.0, 7.0), 5.0 (3.0, 7.0) and 5.0 (3.0, 7.0) respectively.

There were significant differences between the Low-Fat Seaweed Pesto and High Fat Seaweed Pesto (Z= -5.073, p<0.001), Low Fat Seaweed Pesto and High Fat Frozen Seaweed Pesto (Z= -5.589, p<0.001), Low Fat Seaweed Pesto and Medium Fat Seaweed Pesto (Z= -4.045, p<0.001).

There was a statistically difference in overall consumer acceptance depending on what seaweed pesto sample was tested, X^2 (3) = 36.076, p<0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at p< 0.01. Median (IQR) perceived overall acceptance levels for the Low Fat, High Fat, High Fat Frozen, Medium Fat were 3.0 (1.0,6.0), 6.0 (4.0,7.0), 6.0 (4.0,7.0), 5.0 (3.0,6.75) respectively. There were significant differences between the Low-Fat Seaweed Pesto and High Fat Seaweed Pesto (Z= -5.006, p<0.001), Low Fat Seaweed Pesto and High Fat Frozen Seaweed Pesto (Z= -4.610, p<0.001).

5. Results of Dried Seaweed Crackers and Seaweed Crisps

5.1 Seaweed Crisps

Using 1 mm dried Sea Spaghetti for a seaweed crisp, four flavour samples were produced with equal amounts of seaweed in them. Figure 19 shows the overall acceptability of a consumer trial conducted with the dried milled seaweed in the final product.

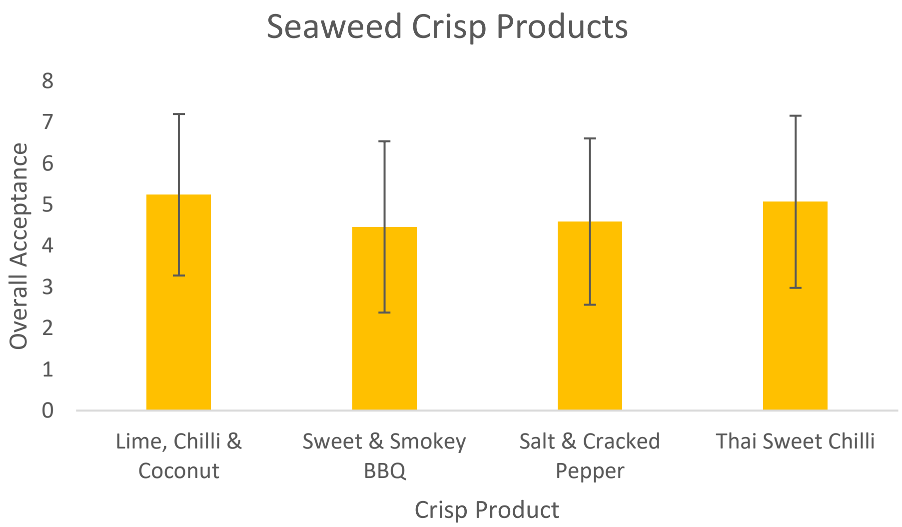


Figure 19: Seaweed crisp overall acceptability

There was not much variation of overall acceptability across the four flavours, however the lime, chilli and coconut appeared to rate highest in overall acceptability (5.24). None of the flavours reached the consumer acceptable rating of 6.0.The results suggested that the data was non-parametric due to the Shapiro Wilk test being below 0.05 for all consumer testing.

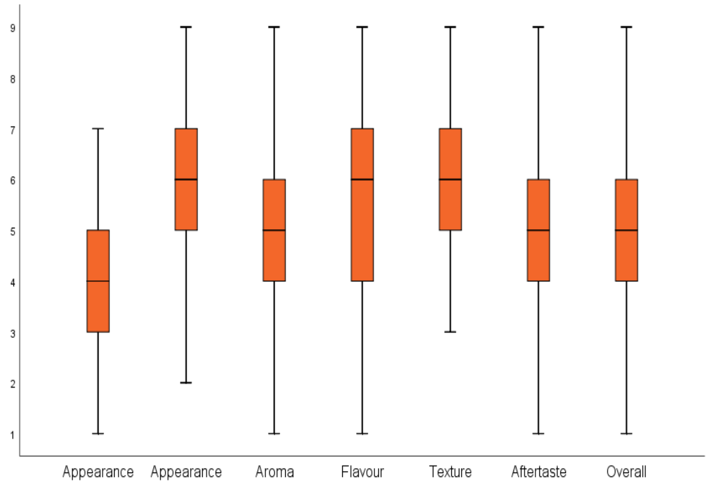


Figure 20: Boxplot of Seaweed Crisp results

The median and percentiles were further investigated and highlighted in represented as Median (25% and 75% percentile), for this consumer analysis 58 participants were evaluated, Female = 40, Male = 19 (Figure 20).

There was no a statistically difference in consumer acceptance towards appearance depending on what seaweed crisp sample was tested, X^2 (3) = 2.363, p = 0.500. Median (IQR) perceived appearance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli was 4.0 (3.0, 5.0), 4.0 (3.0, 5.0), 4.0 (3.0, 5.0), 5.0 (3.0, 6.0) respectively.

In addition, there was no a statistically difference in consumer acceptance towards aroma depending on what seaweed crisp sample was tested, X^2 (3) = 5.697, p =0.127. Median (IQR) perceived appearance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli were 5.0 (4.0, 6.0), 5.0 (4.0, 6.0), 4.0 (3.0, 6.0), 6.0 (4.0, 7.0) respectively.

There was a statistically difference in flavour acceptance depending on what seaweed crisp sample was tested, X^2 (3) = 16.392, p = 0.001. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at p< 0.01. Median (IQR) perceived flavour acceptance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli, were 6.0 (4.0,7.0), 5.0 (3.5,6.0), 4.0 (3.0,6.0), 6.0 (4.0,7.0) respectively. There were significant differences between the lime, chilli and coconut - salt & cracked pepper (Z= -3.096, p = 0.002) and the salt & cracked pepper - Thai sweet chilli (Z= -2.604, p = 0.009).

There was not a statistically difference in consumer acceptance towards texture depending on what seaweed crisps sample was tested, X^2 (3) = 5.473, p = 0.140. Median (IQR) perceived appearance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli was 6.0 (5.0, 7.0), 6.0 (4.0, 7.0), 6.0 (4.0, 7.0), 6.0 (5.0, 7.0).

There was a statistically difference in aftertaste acceptance depending on what seaweed crisp sample was tested, X^2 (3) = 14.837, p = 0.002. Median (IQR) perceived appearance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli was 5.0 (3.5, 6.0), 5.0 (2.0, 5.5), 4.0 (3.0, 6.0), 5.0 (3.0, 6.0). There was a statistically difference in consumer acceptance towards overall acceptance depending on what seaweed crisps sample was tested, X^2 (3) = 14.622, p = 0.002.

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at p< 0.01 Median (IQR) perceived overall acceptance levels for the lime, chilli and coconut, sweet & smokey bbq, salt & cracked pepper, Thai sweet chilli was 5.0 (4.0, 7.0), 5.0 (3.0, 6.0), 4.0 (3.0, 6.0), 5.0 (4.0, 6.75) respectively. There were significant differences between the lime, chilli and coconut - salt & cracked pepper (Z= -2.767, p = 0.006) and the salt & cracked pepper - Thai sweet chilli (Z= 1.804, p = 0.071).

5.2 TDS response rate and significance graphs for Seaweed Crackers

The overall acceptability of seaweed crackers using varying levels of Wakame and Sea Spaghetti is highlighted below (Figure 21).

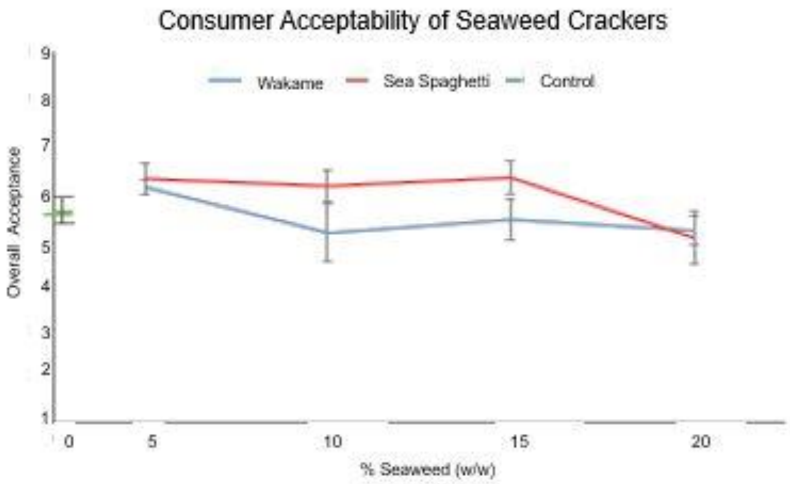


Figure 21: Seaweed cracker with two species of seaweed and different levels added

The Sea Spaghetti demonstrated higher valence than the Wakame over the range of 5 to 15% seaweed investigated. The crackers with up to 15% Sea Spaghetti reached a consumer acceptability score of 6 and above. However, beyond 15% there was a cut-off point as a noticeable decline in acceptability was established for the Sea Spaghetti cracker becoming in line with the Wakame cracker.

The error bars indicate the range of data was consistent with the 5 to 15% (0.35) Sea Spaghetti crackers; however, with the addition of 20% Sea Spaghetti the error bars increased (0.56). The 5% Wakame cracker reached consumer acceptance levels at 6.10 where the error bars were at their lowest (0.17). As 10% Wakame was added to the cracker the variance of data increased (0.61).

The control cracker with no seaweed added to it did not reach a consumer acceptable rating (5.08). Most quantities of both seaweeds added to the cracker were proven more favourable than the control apart from the cut off with 20% Sea Spaghetti (5.00).

The overall acceptability of both species with the varying amounts added was indicated in Figure 22 below.

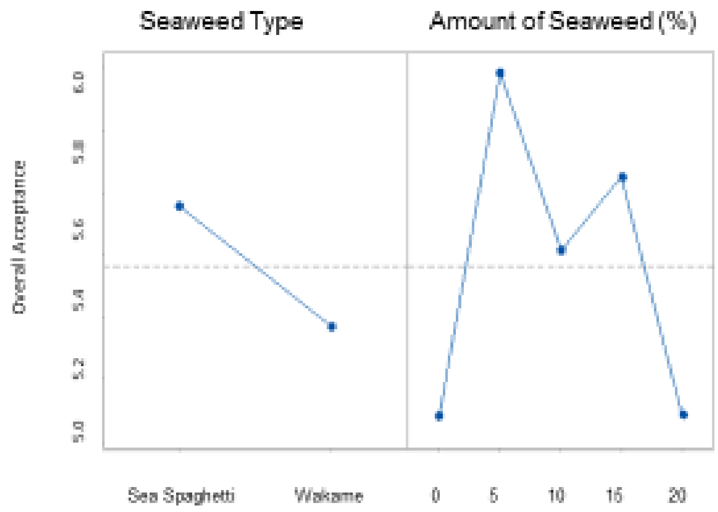


Figure 22: Main effects of Overall Acceptance

The main effects of overall acceptance (Figure 22) of seaweed type generated a change in acceptance scores (F=15.1, df = 1, p = 0.001). The acceptance score changed with concentration of seaweed (F=18-93, df = 4, p = <0.001). The addition of 5% seaweed is acceptable regardless of species with an obvious decline with the addition of 20%. Sea Spaghetti overall has proven to be more favourable.

Dominant attributes from the TDS experiment for each cracker were detected over the significance line with response rate as shown in Figure 23 - 27. The response rate of each panellist was recorded. These attributes were used to help understand the consumer's acceptability by adding some attribute information from a dynamic perspective. A factorial design with three replicates for each seaweed cracker and 6 replicates for the control was established using a statistical software package Minitab version 17 to produce a 30-run test.

Crunchy dominates all 6 replicates of the control samples (Figure 23) followed by sweetness from 8 to 24 seconds. Hardness was also recognised at the beginning of the chewing process in Control 5. No further attributes are identified after 24 seconds.

All three replicates with the 5% Wakame (Figure 24) also indicate crunchy as the dominant attribute at the initial eating process followed by sweetness halfway through. Over 65% participants had finished chewing by 37 seconds.

Figure 24 also shows the three replicates of the 10% Wakame cracker. Cracker E and F have crunchy at the initial eating process followed by fishy with a slight sweetness (F). Fishy was the dominant attribute throughout the eating process with Cracker D. Over 72% had completed chewing by the 38th second.

Yet again all three replicates for the Crackers with 15% Wakame (Figure 25) indicated crunchy as the dominant attribute initially followed by sweet with fishy (Cracker G and I) being dominant towards the final stage of the eating process up to 28 seconds. Cracker H highlighted saltiness as the dominant attribute towards the final eating process. On average over 83 % had completed chewing by the 36th second.

The Wakame Cracker with 20% added (Figure 25) had mixed attributes within each replicate. Cracker J displayed that hard was the dominant attribute at the initial eating stage followed by sticky. Whereas Cracker K highlighted crunchy, hard then fishy as dominant attributes throughout the eating process and Cracker L showed crunchy followed by fishy as dominant attributes. On average over 73% had completed chewing by the 37th second.

Crunchy followed by sweet were dominant attributes observed in the replicates M and N with 5% Sea Spaghetti (Figure 26) with Cracker O having just crunchy as a dominant attribute throughout the eating process. On average over 85% had completed chewing by the 35th second.

In addition, Crunchy followed by sweet were also dominant attributes with the 10% Sea Spaghetti Crackers P and R (Figure 26). Halfway through the eating process fishy was a dominant attribute appearing in Cracker Q and saltiness in Cracker R.
On average over 82% had completed chewing by the 34th second.

All the Crackers with 15% Sea Spaghetti (Figure 27) had crunchy as the dominant attribute at the beginning of the eating process with fishy Crackers S and T and salty in the middle. On average over 68% had completed chewing by the 38^{th} second.

Figure 27 also highlights the attributes specified with the addition of 20% Sea Spaghetti to a cracker. Again crunchy, salty and fishy were the dominant attributes. On average over 72% had completed chewing by the 38^{th} second.

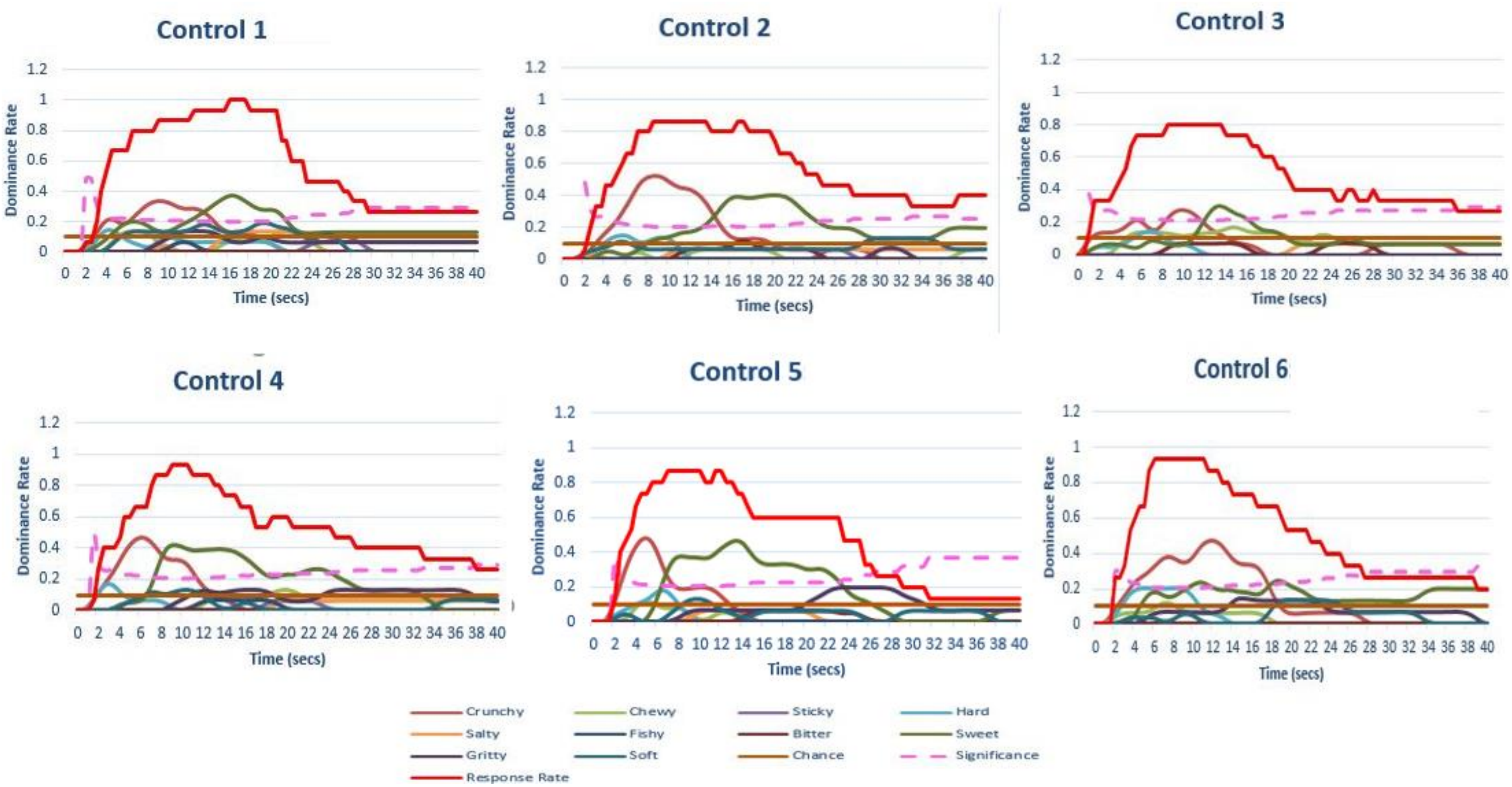


Figure 23: Cracker without seaweed

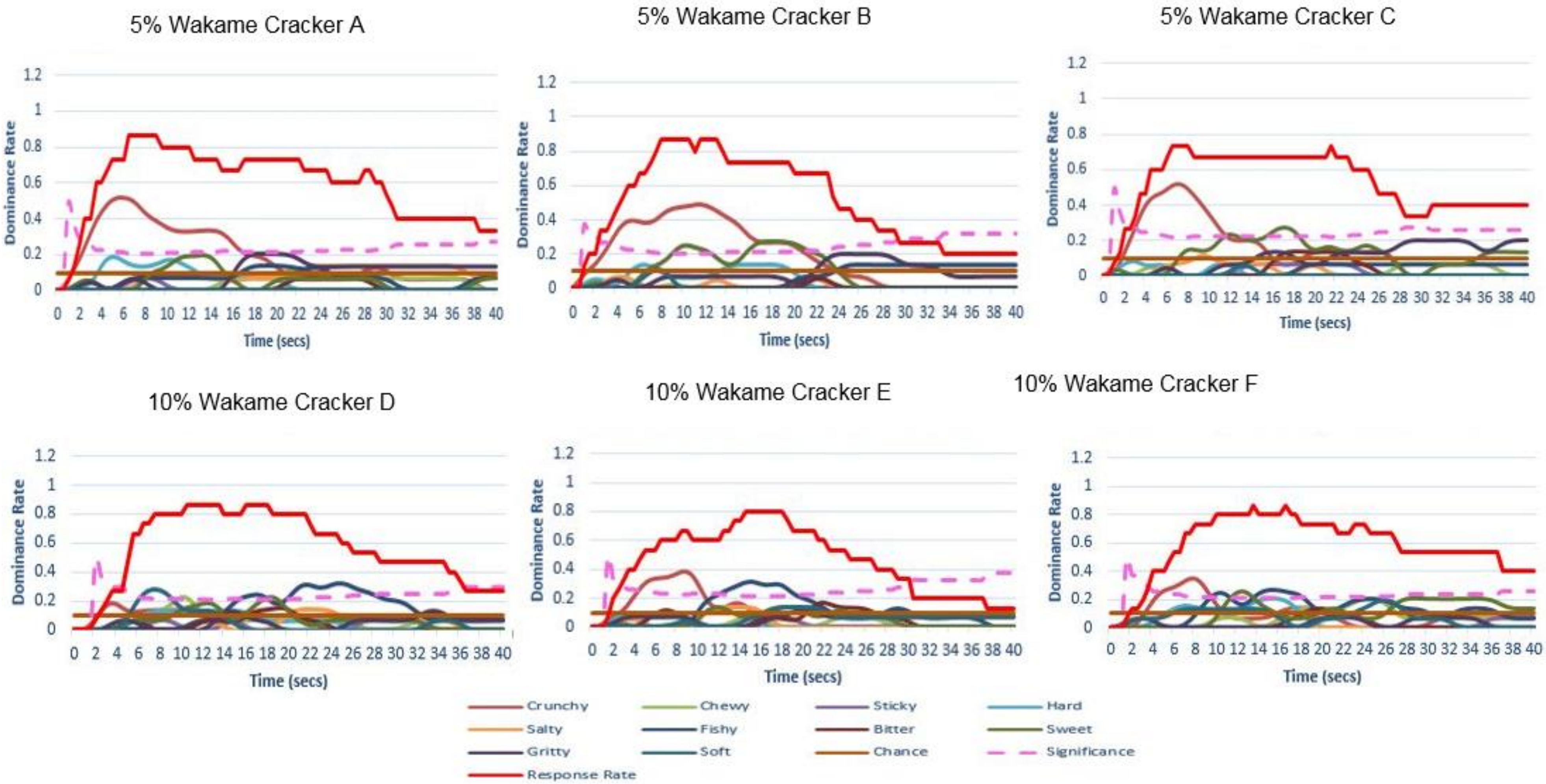


Figure 24: Cracker with 5% and 10% Wakame

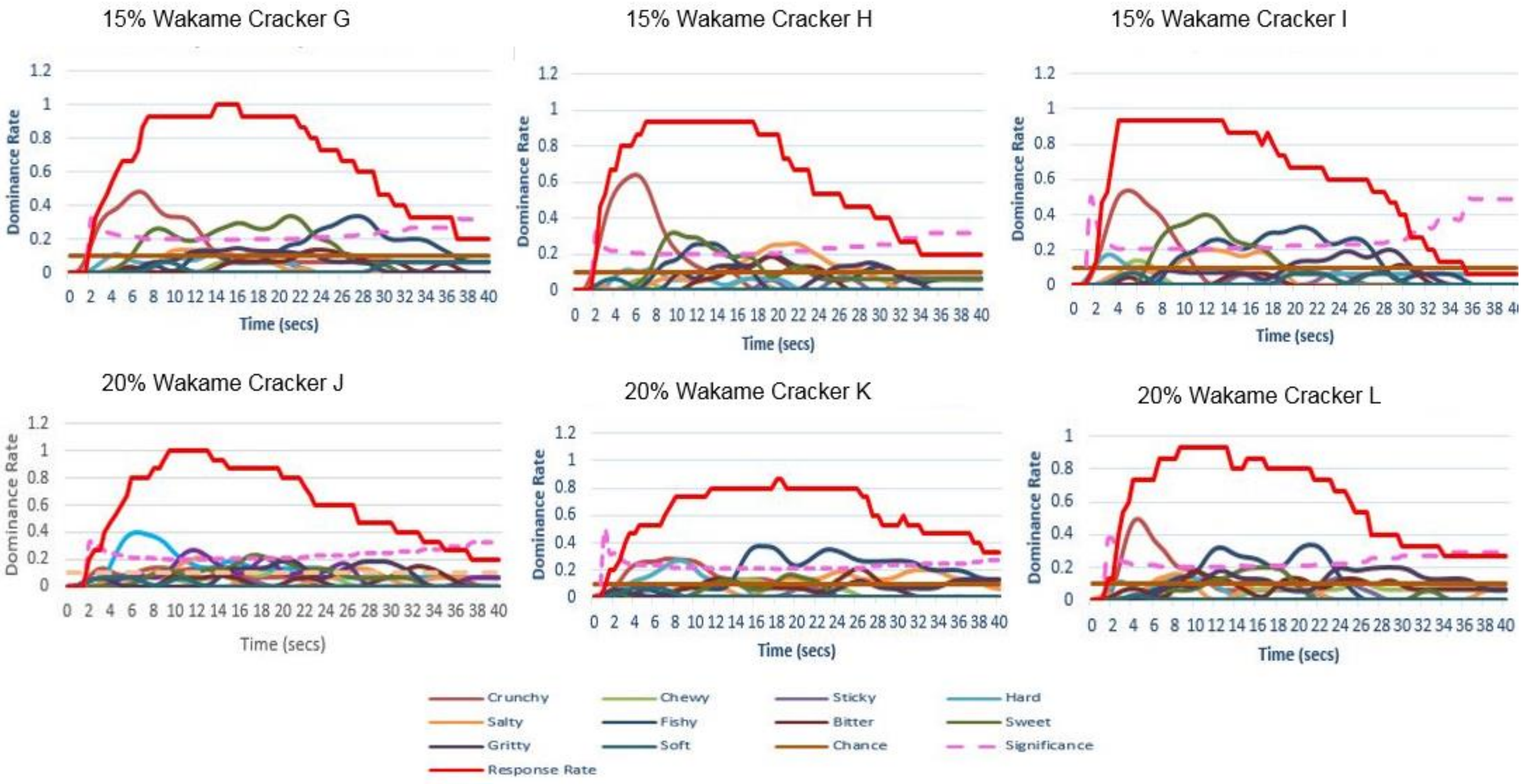


Figure 25: Cracker with 15% and 20% Wakame

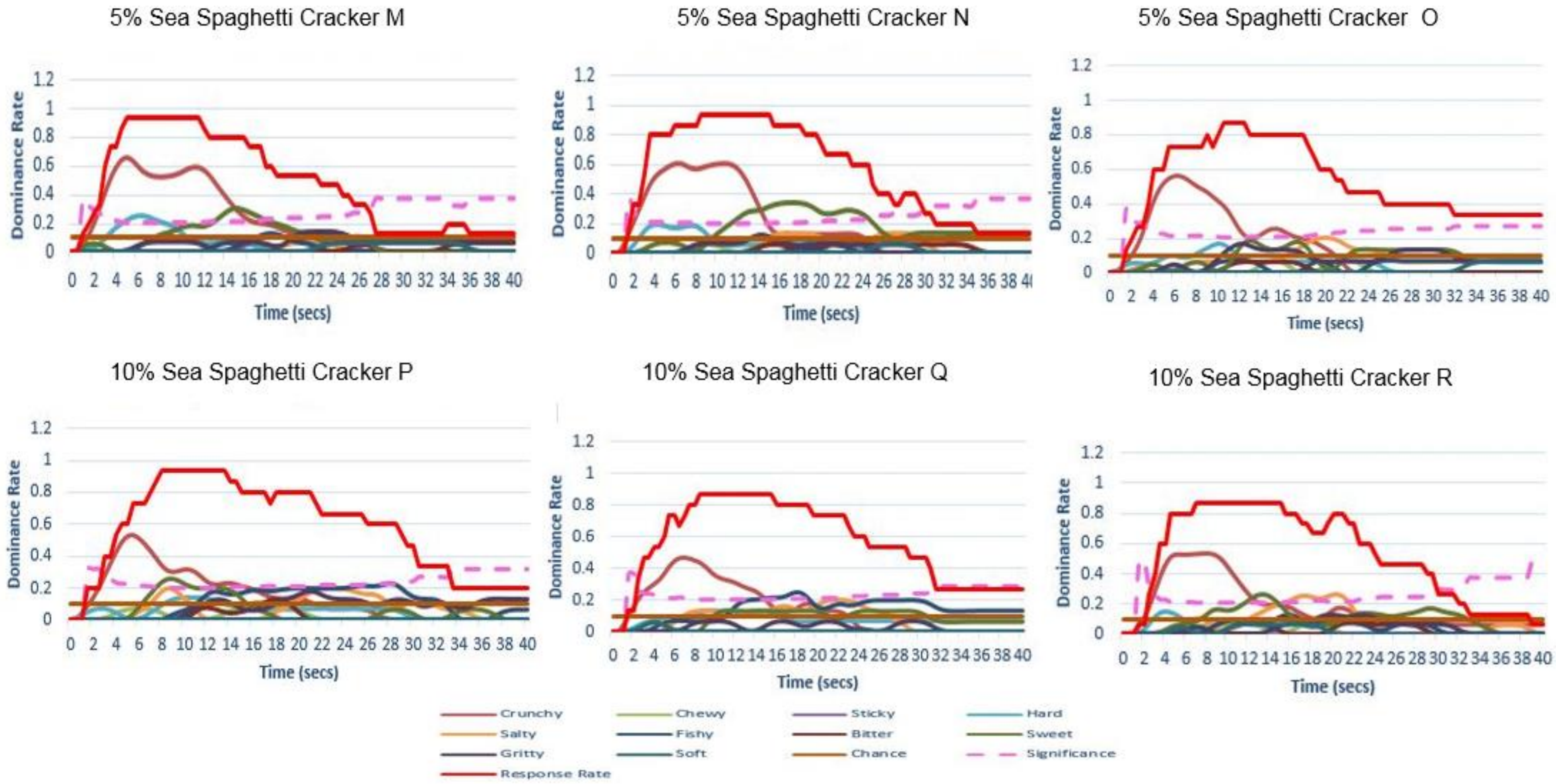


Figure 26: Cracker with 5% and 10% Sea Spaghetti

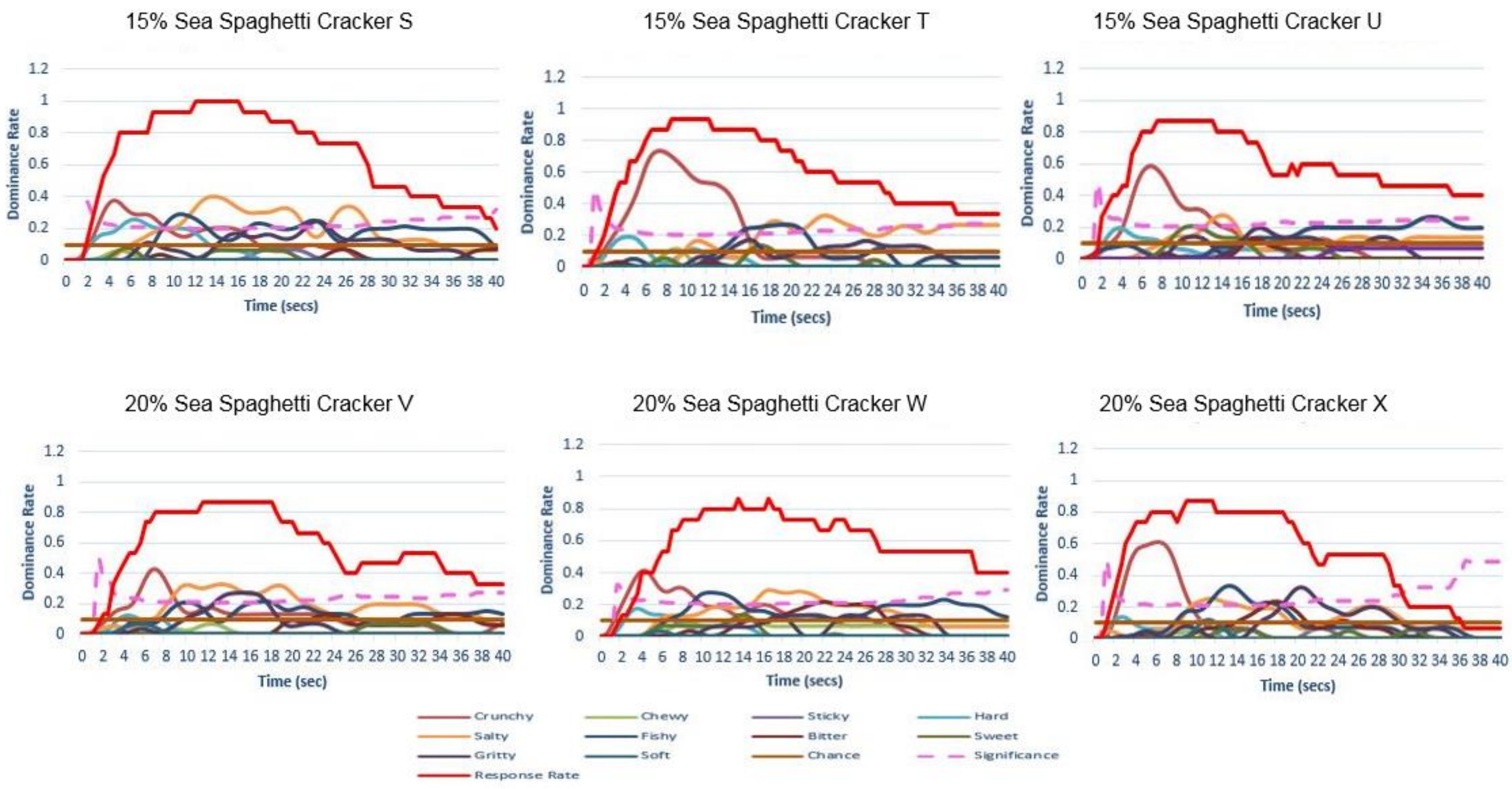


Figure 27: Cracker with 15% and 20% Sea Spaghetti

6. Discussion

6.1 Rehydration Results

In this study, it was observed that Kelp was the toughest seaweed that required the highest strength to burst through each sample. Followed by Sea Spaghetti, Sugar Kelp, Wakame and lastly Dulse. Previous studies have shown that Wakame has a 30-40% water holding capacity, which was similar to the figures presented here, other seaweeds (Mitsuishi Kombu (kelp) *Laminaria angustata,* and *hijiki Hizikia fusiformis*) water holding capacity was around 10-20% water, which is similar to the seaweed samples in this study (Suzuki *et al.,* 1996).

Additionally, the temperature of the water influences the rehydration kinetics and the equilibrium moisture content of the rehydrated product (Krokida and Philippopoulos, 2005), but the water temperature was controlled during this experiment. Similarly, the taste of seaweed changes especially when soaked in water and flavoured liquids, which may affect the flavour of the final product (Nussinovitch, Amos, and Madoka 2013).

It is speculated that this could be due to alginate and the species tested are known to be a rich source of these, a high molecular weight polysaccharide that forms viscous colloidal solutions or gels in water leading to the use of kelp derivatives as bulk laxatives. (Kim and Bhatnagar, 2011). The high cellulose and variation in content of Kelp may explain why Kelp became tougher over time as rehydrated. It has been shown to improve fat and water binding properties of certain products, these include meat, patties (Choi *et al*., 2012 and Oh and Lim, 2011) and sausages (Kim *et al*., 2010).

While some of the seaweeds contained softer tissues, Kelp was to some degree more calcified and contained robust complex carbohydrates. For this reason, it required more force to burst through its tough texture. This toughness and that kelp contains high levels of iodine and sodium, a reduction in the acceptability among the consumers was seen (Molis *et al.,* 2015). Other environmental factors including water temperature, salinity, waves, sea current and depth of immersion also alter the composition of *Laminarin* pre-harvest*;* in addition, these factors are also believed to influence the bio functional activity of *Laminarin species* (Rioux *et al*., 2010).

It is evident that the results from the rehydration trials would distinguish which seaweed would be best for a rehydrated seaweed salad. Kelp, Sea Spaghetti and Sugar Kelp were too tough and based on availability and cost Wakame was deemed the most appropriate species to be used for the new product development of the salads.

6.2 Milling

In terms of the milling overall, the M head was the most consistent in size when comparing the dried and rehydrated seaweed samples. The M head reduced the size of the midrib section of Wakame seaweed when compared to the A and K heads which had a higher percentage left in the sieve over 2 mm. Understanding the role of seaweed in the products, it was deduced that the M head would be used for the salads and pesto once rehydrated. The M head was able to reduce the impact of the mid rib of the Wakame, which through assessment by the researcher deemed the main structure of the seaweed to give a chewy texture.

For the crisps and crackers products, the seaweed milled under 1 mm sized milled product would be deemed appropriate for use in these products from a manufacturing point of view (set by the manufacturers of the crisps). Another significant area was the determination of particle size distribution in seaweed products. Particle sizes have been seen to influence specific properties of products directly such as its taste, extraction behaviour, solubility and colour (Postman, 2016). Like many other food products, seaweed exists in a particulate form; distribution of the size of the particles affects the appearance and the taste of the products. Thus, when designing food products understanding the effect of particle sizes can influence consumer acceptability (Jiménez and Sánchez-Muniz 2010). During the NPD process, the seaweed pieces under 3 mm were too small and often lost in the salads. When using seaweed in products, producers must have a greater understanding of the size of ingredient particles and particle shape. The shape and size of the particle affect the taste and mouthfeel of food.

6.3 Rehydrated Products

The texture between all salads differed in acceptability and were rated considerably lower in the 40 % Seaweed salads (4.0, 3.0, 3.0) than the 20 % seaweed salads (7.0 6.0, 5.0).Overall, the 20 % seaweed salads were more acceptable to the consumer than the 40 % salads as less chewy in texture. The structure of the Wakame had issues with the inner mid rib through the plant, which once rehydrated added to the chewy texture. To reduce the chewy texture within the salad product the seaweed was milled to a smaller size and further reduced by using less seaweed. Peteiro and Freire (2012) demonstrates the structure of the Wakame seaweed species with the midrib (Figure 28). The distinct mid rib growths throughout the middle of the Wakame species and can reach 1.5 to 2 m in length (Marlin, 2018). It can be a chewy part of the whole seaweed plant and by reducing to a size makes it more manageable for eating. Mouritsen (2009) recommended that cooking is required for Wakame to overcome the chewy texture, which may be considered for further new product development. Cooking was not an option for this type of salad product, as the flavour and texture would be affected.

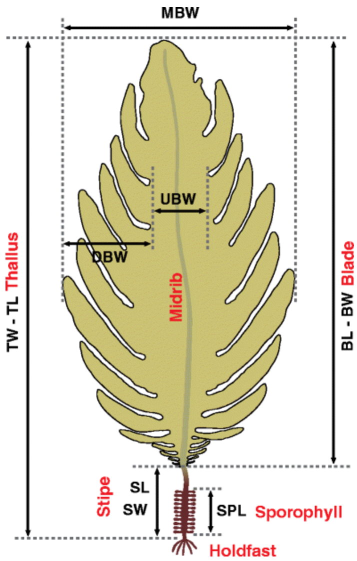


Figure 28: Structure of the Wakame seaweed with chewy midrib through the middle of the plant

Interestingly, the soy and teriyaki salads appearances, aroma and flavour were preferred by the consumer and reached a mean acceptability score of 6.0 and above. In consumer studies, using a 9-point-hedonic scale a mean score of 6.0 or above indicates that the product is slightly liked, liked, liked moderately or extremely liked. It is commonly used to assess consumer acceptability in food products. It is a useful measure to assess the consumer acceptability of the food product and can be used to compare and contrast between many other products. Consumers were asked to rate the appearance, texture, aroma and overall acceptance of each sample using the traditional 9-point hedonic scale (Peryam and Pilgrim 1957). What is interesting is that Seaweed Salads were tested using a wide variety of different consumers from the Dundee area, with no previous experience of eating seaweeds.

Although these high scores, the texture between all salads differed in acceptability and were rated considerably lower in the 40% Seaweed salads (4.0, 3.0, 3.0) than the 20% seaweed salads (7.0, 6.0, 5.0). With the consumer acceptability rating in the food industry reaching 6.0. According to Wadhera and Capaldi-Phillips, (2014) food appearance is an important factor to increase food intake. Humans can create a variety of flavours and change the look of products, but texture should remain constant to avoid dissatisfaction. Kohyama (2015) suggested that the texture of food is one of the most significant sensory properties that constitute palatability.

Lime, Chilli and Coconut salads at 40 % seaweed scored a lower rating than other products within this consumer testing, this may be a flavour issue and combined with a textural issue. In the 20 % seaweed salad Lime, Chilli and Coconut scoring for all attributes was consistently higher than the 40 % (ranging from 6.0-5.0 for the 20 % seaweed salad and 3.0-5.0 for the 40 % seaweed salad). The 40% Lime, Chilli and Coconut salad and 40% Teriyaki salad were rated the lowest for texture (3.0) and the 40% Soy, Mirin and Ginger salad rated 4.0 for texture.

Freezing is one of the oldest methods of food preservation preventing microbial growth for longer storage and allowing for flexibility in manufacture and supply (Evans, 2008). Water is removed from the food matrix with freezing to form ice crystals where the water activity becomes lower and is akin to drying. These ice crystals could potentially reduce the quality of the food product once thawed due to the structures mechanical damage, denature of proteins or limited re-absorption of water during the thawing process. For pesto, on the other hand, most consumers preferred them frozen or freshly rehydrated with the higher fat versions. The biological make up and structure of the pesto is less prone to damage from freezing allowing for a strong comparability of the fresh product. Preference for higher fat foods is apparently mediated by metabolic, sensory and sociocultural (Katz, 2008) and a universal human trait (Drewnowski, 1997).

Texture appeared to be an issue with the seaweed salads, however with the seaweed pesto for the low-fat version, the high fat version, high fat frozen version and medium fat version were rated 5.0, 6.0, 6.0, 6.0 respectively. It appeared that the flavour reduced the overall impression of the low-fat pesto product fat rated 3.0. This could possibly be the seaweed or the reduced fat in the product.

This experiment shows that there is no difference in acceptance between the higher fat version and the frozen higher fat version of Seaweed pesto. This is good for the food industry as the frozen product can have a longer shelf life with no difference to quality when thawed.

6.4 Dried Seaweed Food Products

The addition of 1 mm milled dried seaweed into a crisp product had little variation of overall acceptability across the four different flavours, however the lime, chili and coconut appeared to rate highest in overall acceptability (5.24). None of the flavours of seaweed crisps reached the consumer acceptable rating of mean score of above 6.0. Texture was shown to be a complementary attribute for acceptability, where all products reached a consumer acceptability rating of 6.0 or above, while the lime, chili and coconut and Thai sweet chilli were the standout flavours that also reached 6.0 or above in acceptability by the consumers for flavour.

The new product development involved the use of a twin screwed extruder, which can alter the flavour of the product when cooked at high temperatures. Prior to extrusion a considerable number of flavour volatiles incorporated to the mixture are normally lost during expansion due to steam distillation (Bhandari *et al.*, 2001)

Therefore, the flavour mix with oil was introduced after the extrusion process. Altan *et al.,* (2008) found that product responses on a response surface methodology were affected by temperature and pomace level. Their work showed that varying the levels of grape pomace in an extruded barley snack altered the texture of the final product and showed that that 2 to 10 % of pomace had higher preference levels for appearance, taste, texture and overall acceptability using a 7-point hedonic scale. Seaweeds however, showed that 5 % in a corn matrix was the preferred texture as seen by the textural acceptability of rating 6 or above for all crisp products.

6.5 Temporal Dominance of Sensations

Food products are subjected to numerous chemical and physical characteristics during salivation and mastication (Galmarini *et al.,* 2016). Similarly, the taste, aroma, texture and flavour also change and for this reason, the conventional static sensory methods requiring consumers to average their dynamic sensations in many times miss out some significant information on the food product (Meillon *et al.,* 2009). Thus, Temporal Dominance of Sensations (TDS) is commonly used to cater to such anomalies

(Castura *et al*., 2016). This method is rather significant as it may provide new insights into several taste combinations (Kawasaki *et al.,* 2016). In this case, TDS seems to be somewhat ambiguous as it gives out numerous results for the cracker products presented before the panellist.

In this trial, it was apparent that the fortification of seaweed in the crackers interferes with the texture and alters negatively the acceptability of the natural cracker. However, an excessive amount of seaweed was detrimental where an increase in fishiness and sweetness gave a perceived negative response. In this study, the small number of participants caused a large variation in the data where different participants gave different responses.

While studies conducted showed that the inclusion of seaweed in food products increased the consumers' intention to purchase it, it did not necessarily lead to greater acceptability by the consumers. Oral processing of foods is one of the first steps of food consumption and are of great importance to the intake of the food product itself during digestion and absorption. Also providing the sensory attributes necessary to please the consumer and this can affect the overall opinion of the food product. Food products undertake a variation of biochemical and physical changes during mastication and later digestion. Starting from the first bite, to oral manipulation including mastication and transportation, until bolus formation and swallowing. At the completion of oral processing of foods these physical and biochemical changes such as the use of amylase to breakdown simple sugars mean that the consumed food is very different from the food before it was ingested. (Wang and Chen, 2017).

During the first stage of the oral processing of the control samples, crunchy was the initial dominant attribute followed by sweetness. Sweetness and crunchiness where the main attributes for the cracker with 5 % Wakame, which was the percentage of this seaweed species, favoured the most. This could be due to the intense fishiness and sweetness recorded when the percentage of seaweed increased. Those seaweeds which were over 5 % added to the cracker showed attributes intenseness of bitter and fishy and were considered by the consumer to be a reason for scoring these lower in this acceptability trial.

The initial attribute at the first stage of oral processing with the Sea Spaghetti Crackers was crunchy. Sweetness was then distinguished with a 5 % addition to the cracker. There was some ambiguity with the dominant attributes with the addition of 10 % Sea Spaghetti with the addition of 15 % being most favourable. During the mastication and transportation phase until bolus formation, the salty attribute was selected as dominant. Interestingly consumers rated this cracker more positively as the percentage of seaweed increased, compared to the Wakame cracker, which was opposite. TDS may be a very useful mechanism to understand which species of seaweed should be used in which food matrix and requires further study to fully understand its role in selecting species and food matrixes. There may be some ambiguity in the dominance of attributes as stated from Oliver *et al.,* (2018) where findings suggest that the lack of training on the description of terms, alongside the limitations of the methodology to overlook all attributes other than those dominant.

6.6 Upscaling of Seaweed Products

The 20% salads are currently being scaled up in a factory South of England and available to purchase online. The seaweed crisps are being mass produced at a snack factory in Ireland and now available through Ocado, Real Foods, Whole Foods and smaller retail outlets in Scotland. Small recipe trials for the popcorn, crackers, pasta and sauces continue at the development stage with the intention of scaling up in the near future.

7. Conclusion and Future Work

This novel research investigated a combination of consumer techniques such as TDS and consumer trials in relation to seaweed products. The sensory technique TDS enabled an understanding of the sensory changes that occur during oral processing (Cadena and Bolini, 2011). This will benefit the seaweed company during the new product development stage, identifying attributes that are acceptable to the consumer.

Given the results of the study, it was evident that the quantity, species and characteristics of seaweed in food products had different attributes that significantly affected consumer preferences. The study also investigates the acceptability of several products that contained significant amounts of seaweed. In this instance, consumers seemed to prefer lower concentrations in a salad, which contained not only high-quality nutrients from the seaweed but had specific textures, primarily attributed to the swallowing process experienced by the consumer. While seaweed continues to be an alien venture to many consumers, those who bravely explored seemed to have a have interest in trying new products especially those familiar to them such as salads, pesto, crackers and crisps.

There are, however, several limitations to this study that could be addressed in future work. For instance, the study fails to offer products that have a higher concentration of 40 % seaweed. In addition, the results are only a manifestation of participants located in the Dundee area. These may differ if the consumer trials were performed in a more multicultural demographic such as Manchester or London. The rehydration trials were only completed with a small-scale group of individuals working within the food innovation department, albeit trained personnel. Future work could include a consumer trail for the rehydration of seaweed on up to 60 participants. In addition, more species could have been tested in the food products, but Wakame and Sea Spaghetti were chosen due to commercial practises within the industry and availability.

Food matrixes can influence the overall acceptability of food products, and the addition or fortification of food products on this has been well researched. Seaweed, high in fibre, and high in other nutrients, can be added to food products in various percentages. TDS and other consumer studies are a useful mechanism to determine the balance between seaweed addition and consumer acceptability. The products produced in this research project were demonstrated as acceptable at lower concentrations of seaweed with the maximum contained in the crisps at 30 %. This study will help New Wave Foods Ltd promote seaweed into the food market with a range of successful healthier products.

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9. Appendices

Appendix A: Participant Information for TDS and Consent Form

ABERTAY UNIVERSITY – SEAWEED CRACKER

PARTICIPANT INFORMATION AND CONSENT FORMS

Study title: Investigate TDS (temporal dominance of sensations) on a seaweed cracker with varying flours and species and levels of seaweed.

Introduction: You are being invited to take part in a research study. Before you decide it is important for you to understand, why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask if there is anything that is not clear or if you would like more information. You are free to take as much time as you like to decide whether you wish to participate.

What is the purpose of the study? The aim of this research is to understand the levels of seaweed and species of seaweed that are most acceptable in a food product. In this case a seaweed cracker. It uses computer software Compusense for Temporal dominance of sensations (TDS), a recent descriptive sensory method consisting in assessing repeatedly, until the sensations end, which sensation is dominant and in scoring its intensity and acceptability.

Do I have to take part? It is up to you to decide whether to take part. If you do decide to take part, you will be asked to read carefully this information sheet and sign the attached consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

Are there any restrictions for those wishing to take part? You must be over 18 and generally healthy. Also to be interested in trying new healthy novel foods. We cannot recruit anyone with allergies to gluten.

How many experimental sessions are involved? There are 6 sessions. The first session involves the completion of this consent form and questionnaire, which should take around 10 minutes. The next 5 sessions include sampling six different seaweed crackers and inputting your responses on a tablet in the food sensory booths. Each session will take roughly 20 minutes. The task does not carry any medical risk.

As your participation in this research is voluntary, you are free to withdraw from the study at any time, and for any reason. If you choose to withdraw you do not have to explain your decision, and you may request that any unprocessed data collected from you be removed from the database.

Is there an incentive for taking part? Yes. You will be given a £15 amazon gift voucher on completion of the 6 sessions.

Are the procedures and results confidential? All information that is collected about you during this research will be kept strictly confidential. We may share the data we collect with scientists from other institutions, and with the public (see below). However, any information that leaves Abertay University will have your name and address removed so that you cannot be recognised from it. Any information about your identity obtained from this research will be kept private. In any sort of report, we might publish we will not include information that will make it possible for other people to know your name or identify you in any way. You will be simply referred to by your gender, age and possibly some characteristic such occupation or demographics.

What will happen to the results of the research study? Where appropriate, the results of this study may be presented at scientific conferences and published in journals, blogs and the media. You will not be identified in any report or publication. The results of this study will also help us to design future research projects, and possibly lead to applications in the food industry.

Who has reviewed the study? This study has been reviewed and approved by the relevant Ethics Committee in Abertay University.

Whom can I contact for further information? Dr Jonathon Wilkin, Division of Food and Drink, email: [redacted]

Participant Consent

* I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

* I have advised and discussed with the Researcher any potentially relevant cultural, religious or ethical beliefs that may prevent me from consuming the samples under consideration.

* I agree to participate in this study under the conditions set out in the Information Sheet.

Please sign to agree:

Name:

Signature:

Date: